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Instrumentation

IT has been an up-hill task for the instrument engineer, particularly if his equipment includes electronics, to get his ideas and equipment accepted by conventional industry. While the desirability of a limited amount of instrumentation has been accepted for many years it has, nonetheless, been regarded in the main as an appendage to the plant; to be used only if things are going wrong and to provide some quantitative measurement of a product quality that is assessed by some traditional (and sometimes irrelevant) subjective method. But, as each year passes so instrumentation assumes a greater responsibility in industrial processes and even the most conservative production engineers are forced to admit that automation is here to stay.

Fortunately, in nuclear engineering the vital rôle of instrumentation has, from the beginning, raised its status above that so frequently encountered, but to a limited extent nuclear instrumentation still suffers from the influences of the more retrograde industries. On the manufacturers' side development departments have often been the junior partners of mass production teams catering for, say, the radio and television markets and as research has had to depend upon this side of the business for its finance it has tended to receive second priority in any call upon a company's effort. This position too is changing as more companies appreciate the importance of the industrial market and as research and development teams geared to the development of industrial instrumentation increase in size and stature.

In fairness it must be said that without the communications incentive, developments in electronics would have been much slower, but the need to cater for a highly competitive mass market has resulted in the accent being placed upon cheapness rather than upon absolute reliability and integrity. In terms of much industrial instrumentation, mass communications equipment is relatively imprecise; there is always an operator (however unskilled) in attendance and the critical faculties both in sound and sight are in scientific terms low.

One of the most impressive features of instrumentation development in the past few years has been a turning towards building for reliability and the development of components of high integrity. It is also becoming appreciated by customers that reliability does cost money. Where instrumentation is assuming a positive controlling action on a given process, capital expenditure in the purchase of high integrity equipment can be paid for over and over again. As in most industries, it is the economic forces that exert the greatest influence and the financial incentive to produce reactor instrumentation which is both safe and free from spurious fault indication is high indeed. In calculating the optimum complexity of a given installation real figures can be attached to the risk of spurious shutdown or failure-to-trip in an emergency but, unfortunately, it is more difficult to ascribe real probability figures to the failure of components or units. At first power station installations will require to err on the side of over-instrumentation, incorporating redundant equipment while performance data are built up. It is essential then that operational experience be freely circulated whether this be complimentary to the designers and manufacturers or not, in order that hidden weaknesses can be assessed and the extent of the redundancy calculated.

One handicap to development is the limited market that is available for reactor instruments and the limited production that is possible. In this respect the very large programmes mounted all over the world covering nuclear physics research and the spreading use of radioisotope techniques and high energy machines form profitable markets for the development of highly specialized advanced equipment. From the commercial point of view these markets will for many years be of much greater significance than the reactor instrumentation markets, but progress will go hand in hand and the power reactor programme should gain great benefit not merely from the subsidy that the research programme can effect but also from the techniques that are evolved.

While nuclear engineering has in many respects pioneered developments in instrumentation techniques, so too the spread of these techniques to other industries will reflect back into the nuclear industry and the cross-fertilization of ideas will have beneficial effects to both. We can expect the designer to continue to surprise us with his ingenuity and to continue to devise circuits and systems of ever increasing accuracy, sensitivity and speed. It is, however, to the component manufacturer that we must look for one of the most vital advances, in the production of ever more reliable units whose life and consistent performance can be accounted equal to the components used by the mechanical and constructional engineer.

Radiological Health and Safety

THE Veale report on training in radiological health and safety (available from H.M.S.O., price 5s. 6d.) compiled by a committee appointed by the U.K. AEA will be read with keen interest not only in the United Kingdom at whose particular problems the report is directed, but in all countries actively engaged in the development or use of atomic energy. After considering the types of work involved in achieving radiological health and safety the classification and training of necessary personnel is considered. The report concludes that these can be divided into three groups, the first comprising graduates with good honours degrees who can be expected to assume high responsibilities in the field of health and safety, a second category able to assume day to day responsibilities for operations, and a third class of supporting staff. It is estimated that the total numbers requiring training over the next 10 years will be 200 in category A, 300 in category B, and 600 in category C.

An original suggestion that the AEA should set up instruction establishments was opposed and the committee concluded that the Universities could best train category A, the colleges of advanced technology B, and the technical colleges C. The Committee is most positive in its recommendation that a national radiological advisory service should be established, not answerable to the Ministries with regulatory powers, nor to the AEA. The new body should be independent of them all. Its main function would be to provide advice and technical assistance to organizations not able to support their own full-time radiological service but it would also be available to give independent advice to the larger organizations and to lend assistance in the event of an incident. Stress is laid on providing a regional organization to give maximum flexibility and to allow the organization to gain experience of local conditions.

There is little doubt that such a body would provide a great deal of comfort to the many small organizations employing ionizing radiations in their various forms. While great play has been made of the dangers to employees and the population too little attention has been given to date to the problems of the employer, who, although anxious to preserve his reputation and to safeguard his staff, is genuinely at a loss as to the best means of doing it. Specific rules and regulations go a long way to providing outline answers but consultation and advice are vital if the spirit of the regulations is to be obeyed. The Minister for Science may not be the most appropriate Minister to head such an organization but we trust that the recommendations contained in this important report will be given the most earnest and immediate consideration by the Government.

Euratom's Targets

THE third Euratom report, in addition to summarizing the work of the community over the past twelve months, lays stress on the need for real constructional programmes to be instituted in the near future in order that both operating and construction experience be developed in time for the massive introduction of nuclear generation in the years to come. In the most recent evaluation of electricity demands over the next 20 years the report anticipates a twofold increase over the present by 1970, rising to 3.6 times by 1980. The total electricity demand in 1980 is calculated to be 950 TkWh, of which some 370 TkWh will be provided from "privileged" sources of energy. It would be possible for nuclear energy to fill the gap between the privileged sources and the total demand but a more conservative appraisement suggests that between 1965 and 1970 about half will be achieved and between 1970 and 1980 about two-thirds. On this basis, the total power generated by nuclear energy would amount to about 67 TkWh by 1970 and 295 TkWh by 1980. It is suggested that this last could be provided by an installed capacity of 42,000 MW operating on a base-load basis. It is interesting that the report should further amplify this, by pointing out that the units could be supplied by 250 stations of 150 MW each, which suggests that the community is still thinking in terms of what are now regarded as relatively small reactors, both in the United States and the United Kingdom.

Little comment is made on the breakdown of the U.S.-Euratom power demonstration programme, although mention is made of the negotiations at present in hand for acquiring fuel on a hire basis rather than purchased outright. Strenuous efforts have been made in the past few weeks to resurrect the AKS organic moderated project and the latest news suggests that Euratom itself will be providing the difference between its cost and that of a conventional station.

The Commission has decided to give priority to the construction of a prototype reactor using natural uranium and heavy water moderation with a coolant either of organic or heavy water. Its collaboration agreements with OEEC as regards HALDEN and with Canada will greatly assist the preliminary evaluation.

In the field of graphite moderation the Commission can be regarded as covered by the activities in France, by its association with OEEC in the DRAGON project and by the extension of U.K. collaboration to include AGR technology. A technical exchange meeting was held on April 25 and 26 between Euratom representatives and the U.K. AEA. Perhaps it is because only twelve months ago the AEA was adamant that Euratom should not be given access to AGR information that it is proving so difficult to determine the extent of the present hand-over. It is understood that this is by no means complete but that the AEA has gone a long way to meet Euratom requests.

DIGEST...

Surveying Significant News

DRAGON Construction Officially Inaugurated

To mark the beginning of construction on the experimental reactor DRAGON being built at Winfrith, a ceremony was held on April 27 in which a steel cylinder containing plans of the reactor, a copy of the project agreement and coins from the signatory countries was laid in the concrete foundations by Dr. Eklund of Sweden, the Chairman of the Board.

Second Windscale Processing Plant Begun

Work has started on the second fuel element processing plant at Windscale for the treatment of fuel elements irradiated in the civil power stations, signalled by the awarding of a contract to Mitchell Construction Co., Ltd., for the main civil engineering and building works. The project is designed to phase in with the power station construction programme, this particular plant being scheduled to come into operation towards the end of 1963.

Radioactive Substances Bill Given Third Reading

The Radioactive Substances Bill regulating the use and disposal of radioactive materials passed its third reading on May 4. Last-minute modifications included the removal of the clause specifying minimum source strengths to which the Bill applied as these could be interpreted as including quite conventional materials. A proposal to transfer the responsibilities for the implementation of the Bill from the Ministry of Housing and Local Government to an independent authority went to a division and was defeated.

Industrial Savings from Isotopes

In an address to the British Institute of Management Dr. Putman, Acting Head, Isotope Division at Harwell estimated that British industry was saving at least £3½ million annually and possibly £7 million by the use of radioisotope techniques; this is to be compared with the estimated U.S.A. saving in 1959 of $39 million.

General Dynamics Licence Agreement with German Company

Following its agreement with Vickers covering the manufacture of TRIGA research reactors in the United Kingdom the General Atomic Division of General Dynamics has signed an agreement with Gutehoffnungshutte Sterkrade A.G. This last association also provides for the design and manufacture in Germany of full-scale versions of the company's high temperature gas cooled reactor for central station power generation.

Fuel Manufacturing Consortium in Germany

The third company for the manufacture of nuclear fuels in Europe has now been announced. Rio Tinto have joined with Degussa and Mallinckrodt in forming Nuklear-Chemie und Metallurgie Gesellschaft (NUKEM) and the company will take over the existing research and production facilities of the Degussa Nuklear Gruppe at Wolfgang. Rio Tinto are also in partnership in the Austrian firm Austro-Chematom Kernbrennstoff for the manufacture of nuclear fuels and Mallinckrodt with Montecatini, Anglo American of South Africa, and Engelhard Industries in the Milan company, Italatom.

CNRN/A.-C. Nuclear Fuel Development Agreement

The Italian National Committee for nuclear research (CNRN) has signed a Letter of Intent with Allis-Chalmers for the joint development of uranium thorium fuel cycles. The agreement calls for co-operation in the development of a fuel element and for a pilot reprocessing plant to be established in Italy, as well as a general study of suitable reactor systems capable of exploiting the cycle. Total cost of the programme to cover a five-year period is about 4,000 million lire and it is hoped will lead to a practical thermal breeder system.

Boris Kidric Experiments Completed

The International Atomic Energy Agency have successfully completed radiation exposure tests at the Boris Kidric Institute, Yugoslavia. In the most serious accident of its kind six workers were accidentally exposed to heavy radiation in October, 1958, and following treatment at the Curie Hospital in Paris, five survived without much apparent after-effect. The accident has now been re-enacted with a team of 12 French, seven American, one English and three agency scientists and a large complement of Yugoslavs.

Successful DRESDEN Power Trials

Power testing of DRESDEN began on April 15 and continued successfully until May 1 when the reactor was shut down for a planned inspection. While operating at up to 90 MW(e), 25 M kWh have been fed to Commonwealth Edison's transmission system. G.E. reports that behaviour of reactor was "outstanding" with no tendencies to instability.

A Broader Future for OEEC

The Four Wise Men of OEEC who have been considering the future of the organization and its relations with the United States and Canada have concluded that a broader body should be created which will allow the U.S. and Canada to become full members, but its recommendations as to its functions are phrased in essentially vague terms and do not disguise the practical difficulties of making this an operational reality. The present timetable however, calls for the convention setting up the Organization for Economic Co-operation and Development to be signed in June or July.

AEC Simplifies Access Permit Programme

The U.S. AEC has simplified its access permit programme by reducing the number of categories by which classified technical information is made available to participants in the Commission's civil programme. All but two of the 27 categories have been eliminated—the first covers most aspects of reactor technology, while the second is concerned with plutonium production. This simplification should lead to the elimination of a great deal of administration formalities for companies engaged in purely civilian developments.

Emphasis Turning to Large Submarines

In the debate on the long range ballistic missile the Minister of Defence made it known that the Admiralty is to put in hand an urgent study of the requirements for British-built submarines capable of carrying the Polaris-type missile; this would be certain to be nuclear powered. In the defence debate earlier this year the Government was reluctant to commit itself to such a policy. The last statement would indicate a change of attitude and should see a more rapid increase in the nuclear naval programme than could formerly be expected.

Industry Dominates Fuel Element Fabrication in U.S.

A recent analysis by the U.S. AEC shows that in 1959 industry in the U.S. handled 94% of the 110,000 kg of enriched source material not associated with the military programme in the form of UF_6 and thus has taken over responsibility for the manufacture of fuel elements almost entirely. Contracts for fuel elements for the naval programme in the year totalled $200 million, reactor cores being supplied by five different private companies. Certain special elements are still manufactured in the U.S. AEC's own facilities and elements for the plutonium production reactors in AEC-owned facilities run by industry.

Elements Irradiated to 8,000 MWd/t in Shippingport

Although the average exposure in the blanket of the Shippingport PWR is approximately 2,000 MWd/t a significant number of elements have been irradiated to 8,000 MWd/t. Inspection of these has shown that they have suffered little during exposure and give additional confidence to the forecast that the burn-up of stainless steel and zirconium clad UO_2 elements can be as high as 11,000 to 13,000 MWd/t.

Increased Capacity for Oldbury

Following the public inquiry into the building of a nuclear power station at Oldbury-on-Severn it is now apparent that the station will be much larger than the 1,000 MW capacity for which permission was first sought. The plant will be built in two stages with the first of 550 MW to be followed by a second stage of a suggested 850 to 1,000 MW.

Increase in Conventional Power Station Efficiency

The CEGB has announced that during 1959 the average thermal efficiency of the power stations operated by the Board increased from 25.99% to 26.36%. Almost one-third of the total units sent out (approximately 90 T kWh) were supplied by 20 thermal power stations with an average efficiency of 30.67%. The highest recorded was 33.88%.

Work at Culham Begun

A building contract has been awarded to Gleeson, Ltd., for the first phase of construction at the AEA's new laboratory at Culham, some seven miles north-east of Harwell. The first buildings will accommodate ICSE, the Intermediate Core Stability Experiment, which is the machine being built to study the physics and mechanics of high temperature discharges which it is hoped will lead to a better understanding of the instabilities and energy losses encountered in ZETA.

Sources of Instrument Faults

WITH the accent of reactor instrumentation always on fail-to-safety the tendency to design equipment which will give rise to spurious signals which can initiate a shut-down is increased. With research and experimental reactors the importance of this aspect will depend upon the operational commitments and the extent of built-in xenon override but spurious tripping is never desirable and can be costly. Even more will this be true in a power reactor where reliability and continuity are at a premium.

In general terms the reliability factor can be expected to be higher in a power reactor than in a research or test reactor because the first is designed for constant running under standard conditions whereas the last have been designed for flexibility and for the inclusion of experimental equipment, both of which introduce additional sources of fault, real and spurious. But, whereas a great deal of experience has now been gained in the operation of research and experimental reactors by diverse bodies, the number of power reactors (not hampered by military restrictions) at present in operation is small.

To gain an estimate of the frequency of spurious information causing a hold-up in operation and to see if some common factors governing these faults could be found, *Nuclear Engineering* circulated some 25 operators with standardized questionnaires requesting information on their experiences. Of these, approximately 50%* have replied and the following is an analysis of the information given. A strict statistical analysis is not possible due partly to the smallness of the sample, partly to the different interpretations that were placed upon the questions, but chiefly because of the particular conditions governing the operation of the reactors, the differing philosophies adopted in the original designs and the varied emphasis placed on anticipating faults. The analysis was not confined to spurious faults which initiated trips but to all instrumentation mal-functions.

Clearly, the interpretation of the evidence must contain a large subjective element and the weighting of the various factors is open to criticism. Where repeated trouble has been encountered in one particular unit or component as a result either of a basic weakness in design or manufacture some attempt has been made to modify its influence on the overall picture, but reactors were chosen which had been in full operation for at least 12 months so that all the commissioning "bugs" should have been eliminated. Where information has been included on experimental equipment tied into the main reactor instrumentation this is taken as referring to the system as a whole.

With the reservations and limitations quoted above, certain general conclusions can be drawn.

Spurious Tripping an Important Factor

In the first place, spurious tripping is clearly an important aspect which tends to have been better countered in the larger test reactors, where the consequences are more serious. The integrated figures show that of the total number of unplanned shut-downs approximately half were caused by spurious signals from the instrumentation. On its own this figure is not particularly significant and may only serve to point the high reliability of the reactors, particularly when it is compared with the number of planned shut-downs (varying from zero to 600/an. with a mean corresponding to once per day), which showed an average of five times the unplanned figure. The ratio is, of course, variable from plant to plant, but the majority differed little from the mean. Of great significance is the fact that not one reactor was able to claim a clear year without at least one trip resulting from spurious information and even only once a quarter was unusual. In terms of research reactor operation this figure represents no more than an irritation, but such a record from a power reactor working on base load would be nigh disastrous.

Electronics Troubles

Turning now to the causes of spurious signals; as must be expected, the majority emanate from the electronics—the "black boxes," and in particular the d.c. amplifiers. On the whole, the record of the sensing elements (chambers, counters, etc.) is good. With electronics (and the amplifiers) carrying the responsibility for so much of the instrumentation it would be indeed surprising if this were not so. Furthermore, the necessity for improving reliability is generally recognized and a great deal of effort is being expended in this direction. Where two out of three systems have been adopted the tendency for faults to cause actual trips is smaller, but the difference between this and, say, the auctioneering system is not as marked as might be imagined. The key to this, perhaps, lies in the answers to questions on what causes the specific faults could be ascribed to. Bearing in mind that this refers to an operator's report, who could be forgiven for placing more stress on deficiencies in design than perhaps the designer would do, the heavy preponderance of maintenance troubles must be viewed seriously.

This is a matter of both organization and system, the preventive maintenance by experienced teams paying handsome dividends. This is a subject that merits intensive study and will tax the operators of power reactors a great deal as their past experience in electronics' maintenance is liable to be limited. A first requirement is quality of personnel. This is not a job for a "good artisan," but needs the attention of top-ranking practical scientists and they must be permanently on duty. In one respect this is more simple to provide in a large power station which can support a large staff than in a small institution, but the administration must be created which can cater for senior men undertaking what in other spheres can be regarded as only semi-skilled work.

The method of preventive maintenance also requires considerable attention. The old adage of "leave well alone" is often applicable to electronic circuits and the routine "poking around with a screw-driver" or the indiscriminate changing of valves can well introduce more sources of error than are rectified. Certain organizations have, however, gone a long way towards making preventive maintenance a success.

An alternative approach is to use a continuous checking system. Monitoring circuits can introduce more problems than they solve, but the combination of d.c. and a.c. systems can allow the integrity of a given circuit to be continuously checked at least from the sensing element through to the final register (whatever form this may take)

* Since compiling the analysis a further batch has been received, leaving only a few outstanding.

Estimate of Relative Liability to Fault Conditions

Group	Demerit Figure	Causes	Demerit Figure
Electronics	50	Maintenance	45
Cabling and Telemetering	25	Design	29
Interlock circuits	16	Human error	15
Others	6	Mechanical damage	9
Sensing elements	3	Others	2

Units	Demerit Figure	Components	Demerit Figure
D.C. Amplifiers	42	Valves	43
Power supplies	26	Relays	40
Cables	20	Resistors, condensers	6
Trip circuits	8	Connectors	4
Ion chambers	4	Switches	2

and include the majority of the units susceptible to trouble. A third approach is to use three-position logic wherein the instrumentation is continuously required to give evidence of proper operation in addition to a go/no-go signal. A great deal more evidence is required before the strengths and limitations of these systems can be fully assessed and much out-of-pile experience will be necessary to prove their fail-safe characteristics before they can be applied with confidence to reactors, but the future of reactor instrumentation could well lie in one of these directions.

Cabling

An area where trouble has been encountered which one would have thought could be avoided is in the connecting leads between units. One suspects that this stems in part from neglect in the design of such a commonplace feature. Mechanical damage, however, figures largely in the causes of these breakdowns and the cabling of research reactors is no doubt more subject to alteration, impermanent positioning and cleating, as well as straightforward misuse than will be the cables in power reactors. Such obvious sources of faults as the use of single-strand wires can be avoided in the original specifications, but this is the type of error that contractors can make either accidentally or to cut costs.

As mentioned previously, the nuclear sensing elements have a good record but it must be remembered that in research and test if not in experimental reactors they will, in the main, be operating at modest temperatures and pressures, and in power reactors, under more exacting conditions, their behaviour may not be as consistent. Probably, however, the more serious problem will relate to the connecting leads within the reactor vault or vessel. The physical instrumentation has also shown proven reliability, although the few faults that have been experienced indicate that there is no margin for complacency and, again at higher temperatures, thermocouples and their connecting leads may be more troublesome.

Power Supplies

The frequency of failure in power supplies underlines the importance that is attached by power station engineers to this section of the plant. Quite apart from the gravity of this problem as regards spurious trips, the accidental failure of the main supplies and emergency instrumentation supplies can have the most serious safety implications. It is difficult to pin-point the main detailed cause of trouble as the failure of generators, storage cells and the switching arrangements have all been experienced. The much increased total power requirement of a power reactor further aggravates the situation and one of the most forceful arguments in favour of the transistorization of reactor instrumentation is to cut down the emergency power demands and simplify switching problems, rather than to save watts *per se* or space. At the same time, a general point of philosophy is raised as to how many individual units should be fed from a single bus bar and to what degree should these be backed up by storage cells and emergency generators. It is difficult to believe that storage cells cannot be made 100% reliable provided that efficient maintenance is organized, but their presence amongst the causes of breakdown and their mention by more than one operator implies that they cannot be installed and then neglected.

Components

Maintenance again seems the key to one of the most common sources of component failure—the relay. There is a great deal of evidence to show that the relay, if of a proven type, made by a competent manufacturer, designed to operate within the stipulated limits and then maintained in such a manner as to retain the correct spring tensions and prevent the ingress of dust, can be a most reliable unit (see *Nuclear Engineering*, Jan., 1959, p. 23). It is not possible from the results quoted to establish a detailed cause of failure and definitely to lay the blame at the door of the designers or operating organizations. What is clear is that the techniques of applying relays to reactor instrumentation have yet to be mastered and there are production and operation problems which must be largely tackled by modified administration rather than in the research laboratory. It is important to note that in the case when magnetic amplifiers have been used these have also not been trouble-free.

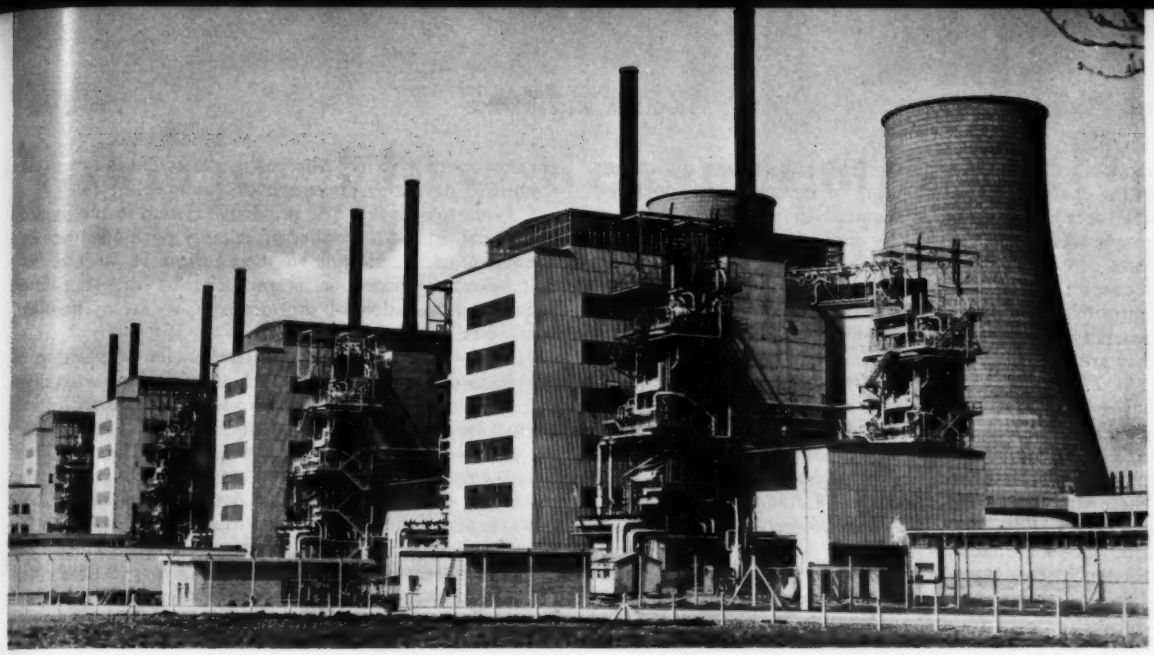
Of similar importance to the relay is the thermionic valve, which one must expect to burn out after a given number of hours of operation; regular replacement does not offer a solution. The life-testing experiments at Harwell have shown that the probability of failure decreases with age for a period considerably exceeding the "guaranteed" life of the tube. From a design point of view, there are certain ground rules which can be adopted such as, avoid the use of matched valves or those requiring special selection, avoid designs which require valves to operate near the limits of their characteristics, avoid the use of valves known to have a limited life such as rectifiers, but this is only a partial solution. More needs to be known of the pre-failure characteristics and of methods of prolonging life although the valve manufacturers are continuously making advances. The provision of ageing facilities, while costly, may well prove advantageous. The transistor may ultimately provide the answer, but present evidence allows one to conclude no more than that transistors should be about as reliable as valves and they are not the panacea for all circuits.

A clean bill cannot be given for that matter to resistors or condensers, although careful design not only circuit-wise but in the engineering of the "boxes," should largely eliminate trouble from these causes.

Conclusions

In the foregoing we have tried to point the moral of the results submitted rather than to quote the statistics, but in the accompanying tables we have ascribed a "demerit figure" to the various items about which data was given in which the higher the number, the greater is the fault liability. It must again be emphasized that this includes a large factor for personal estimate in weighting the results.

We should like to express our thanks to those who completed the questionnaires so frankly and ask those who have not yet been able to supply information to do so as soon as they can. We can then publish a second analysis should this show different trends. We should also be glad to receive comments on the type of information most needed with a view to carrying out a more detailed survey in, say, 12 months' time.



Automatic Protection for a Gas Cooled Reactor

By B. E. ELTHAN, B.Sc., M.I.Mech.E., and M. J. COWPER
(Authority Health and Safety Branch, U.K.AEA, Risley)

TO secure the safety of a nuclear reactor it is necessary to provide system protection against changes in the operating characteristics which could lead to an unsafe state. As the temperature attained by the fuel elements depends on a balance between heat generation and heat extraction the main problem is to avoid an out of balance in the thermal state so that fuel temperatures do not rise high enough to cause a release of fission product activity. Protection against this is achieved by prevention and containment, the former being provided by automatic and manual action. It is proposed to discuss only aspects connected with automatic action. An advantage of such action is that it contributes towards minimizing the magnitude of an accident should it occur.

Ideal economic considerations require that the maximum fuel element operating temperature should be as near as possible to that set by metallurgical considerations. Additional limits are imposed by safety requirements and the inaccuracy of estimating the maximum permissible can temperature from a limited number of measurements.

For example, in attempting to determine the ability of any given design to protect against major faults such as blower or circuit failure one is often concerned with the time taken to attain the first peak of fuel temperature and the temperature margin available between this temperature and the melting point of a Magnox can. In the hypothetical case of a blower failure without control action this temperature margin is usually of the order of 80°C while the time interval may be 1 to 2 minutes. Any error in the initial setting of fuel element temperature or any serious error characteristics in the trips initiating control rod action could adversely contribute to a potentially serious situation.

The estimation of fuel element temperature is complicated by the wide divergence between the large number of fuel channels and the small number of thermocouples permissible within the core. The estimation of temperature is dependent on a number of factors; the accuracy of predicting these is limited at any distance from the actual measuring point. It follows that certainty of measuring the highest fuel can temperature is strictly dependent on a knowledge of its location and the proximity of the nearest measured element. Because of this, temperature trip levels are dependent on the confidence one places in these estimated temperatures. Practice has yielded a realistic number and distribution of measuring points which give a reasonable guarantee that the normal temperature state of the core can be deduced with acceptable accuracy.

Protective System

A limitation on fuel element temperature is in itself inadequate for reactor protection and a penultimate guard must be provided. This is arranged by deriving a shut down action from a group of variables when the value of any one of these exceeds predetermined limits. These are chosen because abnormal values in any one of them could give rise to excessive fuel element temperatures. In a gas cooled reactor these variables are generally flux, period, flow, pressure and gas temperatures.

1. *Fuel Element Temperature.* Because the major hazard in a reactor resides in the fission product content of the fuel the ultimate trip parameter in the protective system is fuel element temperature. The number of temperature sensors used should always be sufficient to detect adequately the highest mode of heat flux arising from flux instabilities and yet allow an economic trip level. Since each one of these measurements must be capable of initiating a reactor trip itself it follows that if a three line safety protection system is used then each measurement must be triplicated and one fed to each safety line. In cases where it is not possible to triplicate the same measurements three measurements in close proximity must be made to ensure the consistency of safety logic. Since the position of the thermocouples is dictated by a compromise between highest temperature and fastest response, they should be located at some point below the top fuel

element in a vertical channel. This gives rise to difficulties in the charging and discharging of elements and considerable detailed attention is required to position a thermocouple which can reliably function as trip sensor. Some form of cable connection with a weak breaking section or a contact device between element and installed core circuitry may be adopted. Thermocouple contact devices are generally considered unsuitable for safety signals because they are subject to errors and time lags.

2. *Thermal Flux Measurements.* In large gas cooled power reactors it is possible for the flux distribution across the core to become asymmetrical and to vary in space and time. The number of thermal columns used in a reactor must be adequate to detect the highest mode of this flux. These flux instabilities occur at the higher temperature and power levels where the main protection is a flux level trip. The ion chambers associated with these trips are so distributed that there is at least one per thermal column: with a three line system each measurement is triplicated so that instrumentation in any one column can initiate shut down. At lower power and temperature levels the main protection is provided by a period trip and less instrumentation is required because of the more stable nature of the flux. Despite this at least three instruments are necessary for a three line protective system distributed one per thermal column.

Because the nuclear instrumentation may not always react quickly enough to protect the reactor from an excessive rate of reactivity increase particular attention must be given to the design of the control rod system to ensure that this situation cannot arise from mal-operation.

3. *Pressure Measurement.* The reactor must be protected against failure of the pressure circuit. This protection is normally achieved by a trip at low pressure or by one derived from a rate of change of measurement. The setting of pressure level trip is necessarily low to account for system pressure changes while a rate of change of pressure confers the advantages of a fixed trip setting and an immediate signal before the level has fallen to an unsafe condition.

4. *Flow Trips.* These may be provided either by measuring the flow direct from each gas circulator or indirectly by such methods as circulator shaft rotation or monitoring the supply to circulator drives. Indirect methods often cannot detect flow changes caused by external means such as duct valve operation and consequently they must be suitably elaborated to cater for these effects. Because of the unpredictable nature of these changes the direct method of measurement is to be preferred but nevertheless the relative probability of failure of both systems must be taken into account. As the total flow is usually variable over a wide range fixed level trips of this type act only with low settings. When a change in flow occurs the sector control rods in a large reactor which normally respond to a change in gas temperature will reduce power. It should be noted that in the event of a failure or mal-operation of this reactivity control together with a proportional reduction in gas flow from all circulators, no trip action is called for from the flow sensors and reliance must be placed on the fuel element temperature trips. Considerations such as these suggest that a flux to mass flow ratio trip has much to commend it. Under these conditions a trip derived from gas outlet temperature can mitigate the deficiencies of a low flow trip.

On the total loss of gas circulator drive or on flow trip operation the blower drive is usually arranged such that it will be taken over by a pony motor when the circulator speed falls to a certain level in order to prevent reverse gas flow in the system. Alternative protection is to provide a positive device to prevent back rotation.

5. *Protective Logic.* The protective system in the nuclear station consists of a number of suitably positioned sensors connected to the shut-down mechanisms in such a way that adequate protection is provided by the shut-down action and operation of shut-down is, so far as possible, guaranteed.

The problems associated with the choice of position of the sensors has been mentioned and it will be assumed that they have been arranged in such a way as to initiate shut-down action under any conceivable condition when the parameter which they measure exceeds a certain limit. It is further assumed that any delay between a particular parameter reaching a dangerous level and initiating shut-down action is sufficiently small to prevent damage to the reactor. The ultimate trip parameter is fuel element can temperature but because of the limitations previously discussed additional trip parameters are chosen which should operate prior to the initiation of this trip. These provide a penultimate guard and are chosen to be as closely related as possible to the faults which cause an excessive rise in fuel temperature.

The design of components used for a protective system should be of a high order and fail safe. In practice, however, components cannot be guaranteed to fail safe and each physical parameter used to initiate a trip must be measured by more than one sensor and its associated equipment. To avoid any one fault inhibiting protection a minimum of two lines operating in parallel between sensors and shut down mechanisms is required to give adequate protection. To maintain the reliability and accuracy of this system, proof testing and maintenance during operation is essential and with one line out for this purpose it is necessary to install at least three lines and hence three sensors per trip parameter. More than this confers greater safety but, if properly maintained, a reasonable and acceptable compromise between capital, maintenance costs and safety can be shown to lie in the use of only three lines. Although connecting these lines in a one out of three trip system is ideal from the safety viewpoint, a two out of three system is invariably adopted. This confers the advantages of limiting shut down due to spurious tripping and affords test facilities under operating conditions.

In order to conform with the above logic during the maintenance of any channel the remaining two channels should be connected in a one out of two manner.

6. *The Rôle of the Operator.* Although it is usual to provide an operator with an emergency button to shut down the reactor, no credit can be given to this in considering the safety of a reactor. It is essential that shut-down arising from any fault is fully automatic in order to preclude any arbitrary assumptions about operator limitations. A fault might arise in which observation of a single instrument could lead to a different action being taken by the operator than that which would ensue from an examination and comparison of all instrumentation. Modern control is so complex that it is quite possible for an operator to come to a wrong decision by taking into account only some of the observations available to him, or alternatively to come to the correct decision after too long a delay. The automatic protective system on the other hand is connected only with sensing a departure from some preset trip level and hence will react quickly consistent with the fault requiring correction.

The rôle of the operator should therefore be to take long term corrective action, as indicated by instrument and warning systems.

Neutron Flux Measurement at Elevated Temperatures

By A. L. GRAY, B.Sc.
(*Chief Physicist, Plessey Nucleonics, Ltd.*)

THE current search for greater power densities and higher efficiencies in reactor cores has produced a wide variety of designs for which coolant temperatures as high as 1,000°C are proposed. As yet most of these designs are still on paper but two major projects are under way in this country, AGR and DRAGON, using coolant temperatures of 550°C-650°C and 800°C respectively. Both these reactors, however, are relatively large and operate at fluxes high enough for the radiation detectors associated with the normal neutron flux instrumentation for control purposes to be situated in the shielding. Here the temperature is well within the range of currently available detectors. As far as large land-based power reactors are concerned this is likely to be so in most future systems as, for reasons both of economy and safety, the large concrete biological shield commonly employed must not be allowed to rise far above ambient temperatures, and the most convenient site for the detectors where the flux levels are adequate, is in a thermal column in this shield.

Serious problems in detector designs are, however, raised by the zero energy experiments associated with these reactors and by the requirements of reactor physicists for measurements of flux distributions and spectra within high temperature cores where the detectors are in the coolant stream. In zero energy reactors such as ZENITH the core temperature is produced by external means and the peak neutron flux in the core is only of the order of 10^8 n/cm² sec. Thus the sub-critical flux even in the core is barely adequate for satisfactory control. In reactors of this type the detectors are usually located in the reflector or on the edge of the core itself and, apart from severe space restrictions around the small core, the detector and its associated leads must operate at very high temperatures for long periods without attention. Even more severe problems are met in detectors for flux distribution measurements, as they must usually be capable of movement within the core, be very small, and operate at the peak coolant temperatures or sometimes higher due to the effects of radiation heating.

The only practicable neutron detectors available at present for high temperature use, as solid state detectors are far more temperature dependent, are gas ionization detectors. These consist basically of six major components, an electrode structure and envelope, insulators, vacuum lead-through seals, a neutron sensitive medium, a counting gas and some form of signal lead, and it is convenient to consider the problems and their possible solutions in terms of these.

Envelopes and Electrode Structures

As might be expected, the problems involved in constructing suitable gas-tight envelopes and electrode systems are relatively easy to solve. Provided that normal good engineering practice for these temperatures is followed, satisfactory electrode and envelope systems can be made. Some difficulty does arise with the choice of material, the common materials with low cross-sections or short half-lives such as aluminium or magnesium or their alloys are unsuitable for reasons of strength, and the low residual activity obtainable with these materials has to be sacrificed. Materials such as stainless steel and the nickel-iron alloys are commonly used but their high neutron absorption means that the designer is forced to use the minimum thickness and weight of material that conditions permit. The use of low cross-section materials such as zirconium and beryllium is rare as yet but is likely to increase in the future, especially for flux distribution measurements where the minimum perturbation of the flux is required.

Corrosion reactions between the detector and the reactor coolant or with the atmosphere around it are not usually serious when materials such as stainless steel are used but corrosion inside the detector by the filling gas of the electrodes or case can prove a serious problem. Corrosion products can become detached from the metal surfaces and be deposited across insulators, causing conduction or breakdown, and insulating films can also be formed between metal contact surfaces, producing noise. Pressure contacts are avoided and welded joints substituted.

The use of springs in the construction must be avoided as far as possible as the choice of materials is very limited;

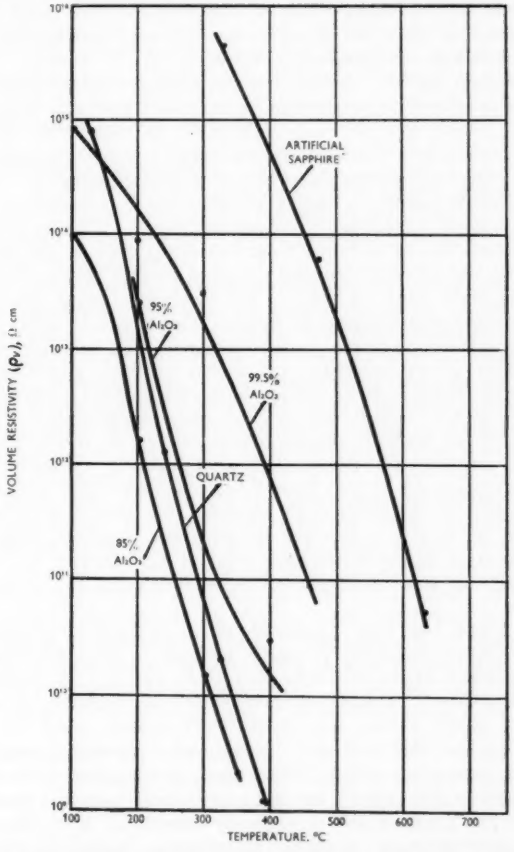


Fig. 1.—Effect of temperature rise on the resistivity of insulators.

at temperatures above 300°C, where springs are essential, nimonic alloys are usually employed.

Care is required in the design stage that suitable allowances are made for the effects of relative expansion of mating parts. This is particularly necessary where insulators are retained by metal flanges.

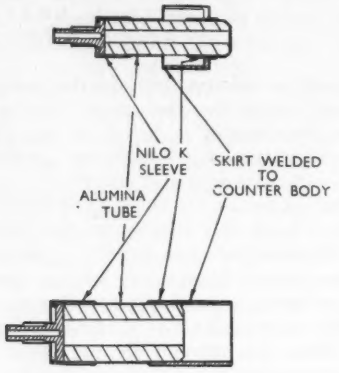


Fig. 2.—Typical ceramic-metal vacuum seals.

Insulators

The requirements for insulators in high-temperature detectors are severe and no completely satisfactory material has yet been developed. High temperatures and high radiation doses limit the choice to inorganic materials and some use has been made of fused quartz, the excellent insulating properties of which have led to its extensive use at ambient temperatures. While quartz is superior to ceramics such as steatite, both in strength and resistivity, the development of alumina ceramics has produced insulators which can be easily fabricated to reasonably tight tolerances and which possess markedly superior mechanical and electrical properties to quartz at elevated temperatures.

The variation of volume resistivity with temperature is shown for a number of materials in Fig. 1. The sintering temperature of alumina is inconveniently high in the pure state and common alumina ceramics contain between 85% and 95% only of Al_2O_3, the remainder being mostly complex silicates used as fluxes. The effects of these on the volume resistivity ϱ_v can be seen in Fig. 1, where the higher purity materials are shown to have appreciably higher resistivities at temperatures above 200°C, although this is not always the case at room temperature. The curve for artificial sapphire is of interest as representing the limiting value for single crystal alumina. Resistivities corresponding to this have been obtained under suitable conditions in 99.99% pure alumina[1] but these high values are difficult to reproduce in practical insulator designs. Artificial sapphire has been used as an insulator but its cost and relative fragility make it unsuitable for general use.

While the bulk resistivity of a material is its most important electrical property for use in d.c. ionization chambers where insulators are usually used in a guard ring construction, in pulse counters, where the insulators across the signal circuit also have EHT across them, it is important that they show no sign of "pulsiness," that is the production of small pulses when in a high electric field. Some of the alumina ceramics containing fluxes are prone to this fault, which is probably associated with microscopic variations of dielectric properties within the body due to imperfect distribution of the fluxing materials. It is important that any material intended for use in a pulse counter be tested under these conditions before it is built in to a detector.

The optimum shape of an insulator to make the best use of its bulk resistivity unfortunately conflicts with the shape most mechanically convenient, which is usually in the form of a washer with a short wide leakage path. .tical insulation values obtainable in an electrode assembly are usually about 0.1 ϱ_v or lower. Thus at a temperature of 400°C using 99.5% alumina, an insulation resistance of rather better than 10^{10} Ω may be achieved. Provided that the insulators are pulse free this is more than adequate for a pulse counter but limits the use of a d.c. ionization chamber to fluxes producing currents of the order of 10^{-10} amp or higher.

Vacuum Lead-through Seals

At room temperature, glass to metal lead-through seals have been extensively used for pulse counters; these take the form of a Carmichael compression seal with quartz insulation where very high values of insulation resistance are required. At temperatures above 100°C the Carmichael seal becomes impracticable and the resistivity of quartz falls too rapidly. At high temperatures many of the glasses used in seals are subject to electrolytic effects and also become noisy, so that the introduction of ceramics becomes desirable. In recent years techniques of brazing between metals and metal films deposited on ceramics have been developed and a variety of reliable ceramic to metal vacuum seals are now commercially available. Most of these rely on brazes between nickel iron alloy components and a suitable metallized ceramic tube or ring. This technique is limited in practice to the aluminas of 95% purity or lower and the resulting seals have upper temperature limits for safe operation of 600°C to 700°C. Designs of typical seals of this type are shown in Fig. 2 and the variation of resistance with temperature for a small seal using 85% alumina is shown in Fig. 3. At 400°C this seal has an insulation resistance of about 10^{10} Ω. Where the shunting effect of this across the electrode assembly is unacceptable, as would be the case with internal insulators of 99.5% alumina, seals can be made to higher purity alumina using the titanium hydride brazing techniques. Seals of this construction are now becoming available with an insulation resistance of at least 10^{11} Ω at 400°C.

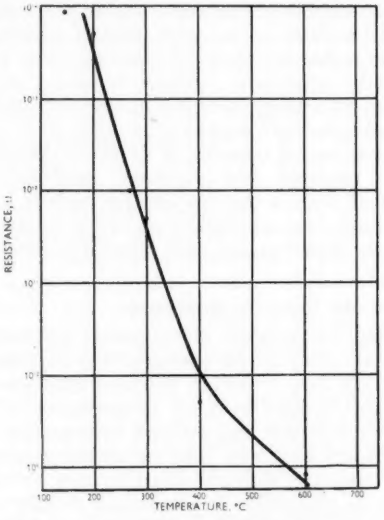


Fig. 3.—Effect of temperature on the resistance of ceramic metal seals 85% Al_2O_3.

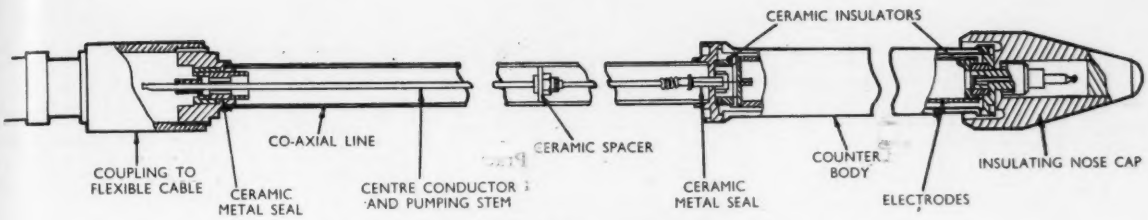


Fig. 4.—High temperature fission counter and coaxial line.

Neutron Sensitive Media

The reactions commonly employed to detect thermal neutrons are the (n,α) reaction of boron-10 and (n,f) reaction of uranium-235. For measurements of fast neutron fluxes fissionable isotopes such as thorium-232 or uranium-238 may be used. These are temperature dependent only in the sense that their cross-sections vary with neutron velocity. In principle any of the normal forms of these materials, boron or uranium oxide coatings or boron tin fluoride gas, are applicable, but in practice no satisfactory method of anchoring boron to metal surfaces has been found for temperatures above about 250°C. Uranium in the form of fired-on coatings of U_3O_8 is strongly adherent up to very high temperatures, so that it is preferred for d.c. ionization chambers as well as fission counters at high temperatures, in spite of the background current due to its alpha emission. High-temperature d.c. chambers using BF_3 fillings have been described in American reports[2] but have not been used in this country.

Gas Fillings

For high-temperature use the gas filling of a counter must have adequate stability under the combined effects of high temperature and irradiation as well as suitable ionization properties. Since d.c. ionization chambers are limited to currents above about 10^{-10} amp at high temperatures due to the combined effects of alpha emission of fissionable coatings, residual activity of the structure and insulation resistance, there is nothing to be gained by using hydrogen, as at low temperatures, to reduce gamma sensitivity. Instead, a suitable inert gas is used and the optimum pressure chosen to give a suitable compromise between sensitivity and saturation characteristics. The noble gases are the most suitable fillings because of their chemical inertness. For pulse counters argon is used but the common practice of using a small addition of nitrogen leads to difficulties in steel counters owing to the formation of nitrides, which have been found to deposit on insulators. Carbon dioxide can be used instead of nitrogen. In d.c. chambers argon is less suitable although often used, as the threshold of gas multiplication occurs at inconveniently low fields, and it is usual to use xenon instead.

Signal Leads

The connection of the electrodes of the detector to the measuring equipment is one of the most difficult problems of high-temperature operation, and no universally applicable method has been developed. Above 200°C there is no suitable truly flexible cable but for d.c. detectors where the cable carrying the polarizing supply can be separate from the collector lead, mineral filled solid dielectric cables are adequate for the higher current ranges of the order of 10^{-7} amp or more. Their resistance is, however, too low for currents below this and rigid coaxial lines using ceramic spacers at intervals must be used. These necessarily impose mechanical limitations in installation and to avoid serious gamma currents the collector lead must usually be evacuated or operated at a reduced pressure. For pulse counters the capacity of solid dielectric cables is too high and they are noisy at high voltages. A possible alternative is to use a high-temperature pulse transformer at the counter so that the cable is not required to carry high potentials and it is used as a matched transmission line. At present gas-filled rigid lines are used for pulse counters, the practical upper limit of length, set by mechanical considerations, being about 20 ft. Fig. 4 shows such a design, the counter being supported in this case by a 4 ft long coaxial line whose inner conductor is itself a tube which is used for pumping and filling the line. The rigidity of a tube permits the use of only one spacing insulator.

The use of a separate sealed volume for the coaxial line avoids the difficulties experienced with some of the early designs where the line and chamber had a common gas filling. This was necessary since at that time only glass to metal seals were available and these had to be located at the cool end of the line. As a result of the temperature gradient down the line the stopping power of the gas in the counter was greatly reduced since its density was much lower in the counter than at the cool end and the counter performance was degraded.

Detector Construction

The considerations discussed above dictate the design of a detector for a given requirement but there are also a number of differences in the techniques of construction for high temperature use.

The operation of any evacuated component at high temperatures requires very high standards of surface cleanliness, and this is equally true where contamination of the counting gas is to be avoided in a gas-filled detector. It is necessary to subject all components to a long process of high-temperature outgassing in vacuum before assembly and great care must be taken in handling clean surfaces after this treatment. So far as possible welding is used in construction as some brazes have volatile components which may contaminate insulating surfaces during final outgassing. Because of the risk of creep in materials under strain when temperature cycled the use of screw threads to clamp components must be avoided and positive location made between flanges. The double-ended type of construction shown in Fig. 4 lends itself well to this technique and is widely used. Final assembly is followed by a long period of outgassing at high temperature and once the detector is complete it is usually life tested for a period of weeks or months at its working temperature.

Choice and Operation

The choice of detectors for a high-temperature reactor is a complex process. Because of the difficulties of maintaining gas purity at high temperatures, counters using gas multiplication are usually avoided and fissile-coated ionization chambers are used either as pulse counters or d.c. chambers. Because of the limitations of the latter at

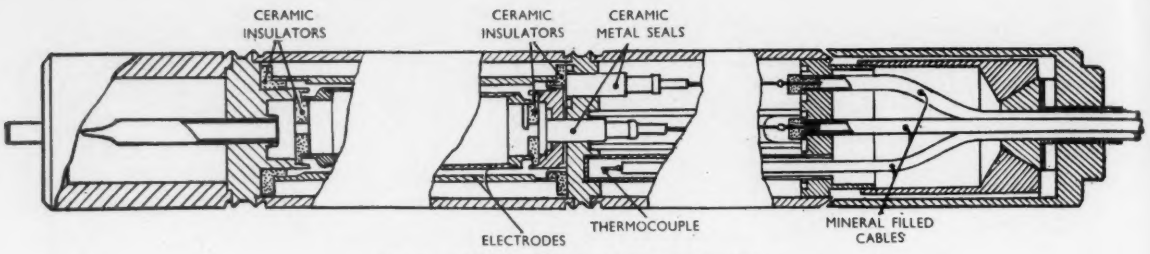


Fig. 5.—High temperature ionization chamber.

low operating currents, pulse counters are usually used for at least start-up and period ranges, d.c. channels being used only for shut-down or power ranges.

In order to limit the operating temperatures the detector positions are often cooled to the region of 400°C where reliable long-term operation is more easily obtained, but this cannot usually be done for flux plotting detectors inserted in the core, although here long life is normally of secondary importance. The need to cool and lag the detector insertion tubes usually imposes limiting diameters on the detectors of the order of 2 in., and this adds to the complexity of design. The final product must be a compromise between factors such as restricted space, high temperature, limited permissible neutron absorption, difficulties of access with rigid connectors, high external pressure, and the need for high sensitivity. For these reasons it is improbable that any standard design of detector will emerge until there is a quantity requirement; at present each reactor imposes different problems.

The result of a particular design process is shown in Fig. 5. This is a 1½ in. fissile coated stainless-steel ionization chamber under development for AERE, Harwell. The construction of this is based on a design of chamber for use in reactor cores due to W. R. Loosemore and J. A. Dennis[3] of AERE, and embodies many of the features discussed above. It consists of a simple double-ended support electrode system using 99.5% alumina insulators held in place by the longitudinal restriction of the outer case. The leads are taken out of the chamber volume through small ceramic to metal seals and connection to the mineral-filled coaxial cables made in a second sealed gas-filled compartment. This chamber will normally operate at 400°C.

Conclusions

Current techniques permit the design of detectors to operate at very high temperatures. Ionization chambers for use at 400°C and fission counters for use up to 900°C are now being made and a further rise is possible.

The design, development and manufacture of detectors of this sort is, however, a costly process and is likely to remain so for a considerable period, until the development of reactors permits some degree of standardization to be obtained. Their principal applications at present lie in high-temperature low flux experimental reactors. Power reactors usually operate at flux levels high enough to permit the detectors to be sited in the shielding. In these, however, there is the possibility in the future of siting detectors inside the pressure vessel but the potential advantages of this are partly offset by increased cost.

ACKNOWLEDGMENTS

The author is happy to express his appreciation of many helpful discussions with the staff of the Counters Group, Electronics Division, AERE, and to acknowledge the permission of the U.K.AEA to discuss the ionization chamber shown in Fig. 5.

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The Purpose of the Computer

By B. MURPHY, M.Eng., Ph.D., A.M.I.E.E.
(*Manager, European Division, Electronic Associates Ltd.*)

THE modern computer is a useful tool, complex but economical. It can be considered and discussed in this light only. Computers are basically used to process and clarify data being presented to human operators in order to simplify the making of decisions. It is by aiding in clarification of thought, by relieving the tedium of computation, and by making extensive computation feasible that computers contribute to progress. Whether a computer study is needed, and what type of computer would be used in any given case can only be resolved by the widest economic considerations. The computer, being a tool, appears in many forms. It may be special purpose or general purpose. Two principal classes of computer exist, digital and analogue.

Digital machines compute by breaking all computations down to arithmetical processes. Trains of pulses represent numbers which can be processed at very high speeds, the basic processes being addition, subtraction and storage. Since all computational problems can be ultimately resolved to these operations, if need be, the digital machine can be used universally. But, it may be, and frequently is, uneconomical and too slow to be realistic or even feasible, as with the pencil and paper computations which it directly mechanizes.

Accuracy is very high, 10 places of decimals being standard. For arithmetical computations; for handling large quantities of numerical data such as accounting insurance statistics, and for much data processing the digital computer is the obvious and only machine to use. For many scientific and technological uses requiring very high accuracy, it is also the best machine. For scientific and technological work its chief disadvantages, at this time, are difficulties of programming, the time taken to obtain solutions, the incon-

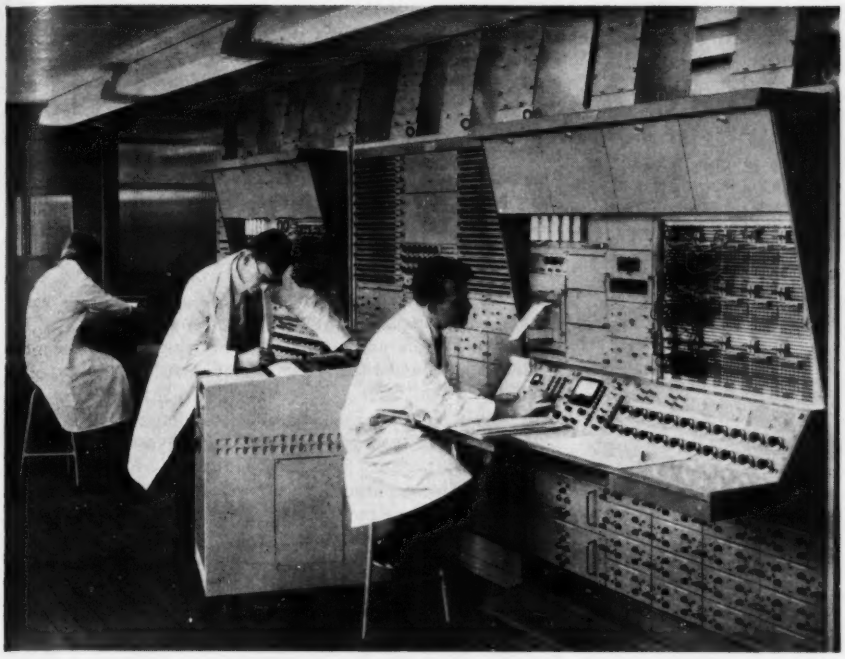


Fig. 1.—Pace 231R computing installation at the U.K. AEE, Winfrith.

venient presentation of results, and the general "loss of contact" the scientist has with his particular problem.

Analogue machines use convenient physical systems, which are, or can be adapted to be, governed by the same equations as the inconvenient physical systems required to be studied. Forms of relatively inflexible analogue computers are scale models of all types, electrolytic tanks, network computers, hydraulic models, wind tunnels, etc. The most useful modern general purpose analogue computers use high gain d.c. amplifiers with feedback to carry out the basic operations of addition, subtraction and integration.

The apparent simplicity of the basic units necessary to perform the fundamental linear operations has led many people, particularly in the U.K., to fall into the uneconomic trap of developing and building their own machines, thus finishing up with a poorly organized, expensive, and frequently unreliable machine with a poor range of non-linear equipment, such equipment being costly to develop.

The facility with which the machines can integrate with respect to time makes them the obvious choice for dynamic problems. Significant advantages of these machines are ease of programming, and of carrying out changes in programme, speed of operation, and direct graphical presentation of results. Disadvantages at present are integration with respect to one variable (time) combined with too low a standard of differentiation which generally eliminates the possibility of evaluating ydx as $yxdt$; and limited accuracy, although modern precision analogue computing equipments (see Fig. 1) carry out linear and some non-linear operations with an accuracy of 0.01%.

There is a wide range of scientific and technological problems where it is not evident which type of machine is best. The continuous development of digital machines and programming procedures and of analogue-machines, if anything, makes the overlap and confusion greater. Protagonists of different forms of computing machinery are frequently guilty of narrow mindedness and even of mental laziness, in supporting their particular type of computing equipment for the study of problems and in ignoring the possible economic advantages of other types.

Some large and important problems in the nuclear and missile industries are being treated by combined analogue-digital machines operating simultaneously with high-speed analogue-digital, digital-analogue converters. Suitable converters are expensive. Considerable attention is also being given to digital differential analysers (DDAs). These can be considered as digital machines with parallel operating units which can be interconnected as with an analogue computer. The claim for DDAs is that they are as accurate as digital computers and as fast as analogue computers. Present commercial machines can fill either claim but not both simultaneously, for accuracy is roughly inversely proportional to bandwidth and is determined by the programming. Indications are that we can expect a significant breakthrough in the near future, but again the machines will be expensive.

The economic considerations on the use of computing machinery are generally obscured by lack of a simple measure of the effectiveness of such machinery. Any "figure of merit" should be some product of accuracy, speed and estimated utilization factor divided by cost. Such a figure of merit would become zero if the accuracy or speed were completely unacceptable. The use of a digital machine for payroll and accounting mechanization may be directly evaluated in terms of the cost of labour saved. The use of computing machines in technical work—where they increase the effectiveness of scientists and engineers and thus increase the speed of development and the assurance of adequate performance—is not sufficiently appreciated by average management, particularly in older established industries.

Fortunately the new industries such as nuclear engineering and missiles had, and still have, difficult technical problems to solve quickly and have a higher degree of technical competence at top management levels allowing the advantages of computers to be adequately appreciated. Hence practically all laboratories, companies or groups concerned with overall aspects of nuclear power have and/or frequently rent large computers of both types. Fig. 1 shows the large analogue installation of the U.K. Atomic Energy

Establishment, Winfrith; similar machines are installed at U.K.AEA Risley, CEGB, The Nuclear Power Group, G.E.C. as well as in most Western European countries.

Nuclear problems commonly treated by computer cover reactor kinetics, heat exchange, temperature reactor stability and distribution control, fuel poisoning, fuel burn up, neutron flux distribution, overall power station stability, control and operation, effects of failures, etc. All these problems can be treated either by digital or analogue computers. At the seminar on "Use of the Analog. Computer in Nuclear Science" sponsored by the International Association for Analog. Computing held on April 21 and 22 of this year in Brussels, Mr. C. Caillet of the Commissariat à l'Energie Atomique, Saclay, quoted several cases of nuclear studies carried out on digital machines and on 0.01% analogue machines cross checked experimentally. He concluded that with adequate care the computation results from the two types of machine could generally be expected to agree to within the order of 0.05%. Melle. Bettembourg of the same establishment reported specially on heat exchange analogue and experimental studies with the same general conclusion. For a wide range of nuclear problems accessibility to a machine, convenience, rate of production and associated direct cost of results would thus appear to be the prime considerations.

The most awkward computational problems are the multi-dimensional partial differential equations. Digitally, there are programming difficulties in ensuring convergence. For a large number of mesh points a large storage capacity is needed together with high-speed and even multiple arithmetical units to reduce the computation time to practical limits. Machines such as LARC and STRETCH, now under development with such problems in mind, presumably largely for fusion studies, are in the £1-2 million class. Still more powerful machines appear economically feasible with the advent of micro circuits and the continued improvements in programming technique.

Analogue computers require large amounts of equipment with the finite difference methods presently used. Extensive studies carried out at the European Computation Centre of Electronic Associates Inc. indicated that surprisingly good results could be obtained in flux distribution studies with a 200 amplifier machine. Dr. Jeffries, of the English Electric Co. at Whetstone, who reported at the Brussels Seminar on the very satisfactory progress of the 1500 plus amplifier machine which he is constructing, also mentioned during discussions that the use of second order difference techniques gave good accuracies with few points. The analogue computer can be satisfactory for flux distribution and complicated heat exchange problems if control elements are to be considered in the same study.

Large, powerful analogue computers are now available with all-electronic non linear units. These can be used in high speed repetitive mode so that with a suitable memory, iterative or random optimization techniques become feasible for solving partial differential equations—particularly the type of equations frequently encountered in chemical engineering, e.g., distillation columns.

The advent of all-transistorized, all-electronic analogue computers (Fig. 2) could make larger and still more powerful computing machines economically feasible as well as being suitable for on-line control uses. Here again, these machines complement the digital computer and extend the range of technical tools.

The use of computers for on-line control is in its infancy. Digital computers are being used for automatic stock control and supply in some automobile plants. Combined digital-analogue machines are being used in automatic railway marshalling yards in the U.S.A. Analogue computers are being used for the automatic dispatching of electric power and rudimentary analogue computers are relatively widespread in control work.

Their use to make decisions is increasing. Fully automatic power stations, distribution networks, chemical plants, etc., are not Wellsian fantasies but questions of hard economics. However, even the biggest present day computers are still far from being able to "think"; their memory capacity, speed of operation and logic being rudimentary.

As computers are an advanced tool, they require well-trained and capable personnel to enable them to be exploited to full advantage. In this respect Continental students of science and technology possibly have some advantages over their U.K. counterparts, in familiarization with industrial requirements and techniques, as well as being better served in their researches. The Universities of Paris, Aachen, Darmstadt, Stuttgart, Gottinger, Braunschwerg, Brussels, Mons, amongst others have large modern industrial analogue computers. Some of them have powerful digital installations as well.

A particularly important present day use is in feasibility studies of new types of reactor when available experimental data may be extrapolated to the maximum. Such studies also focus attention on the further experimental information that may be required thus increasing the effectiveness and reducing the cost of experimental work. Having proved the feasibility of the chosen system, it can be optimized and proved by using a computer to investigate the results of experiment and to direct further trial and assessment.

This aspect cannot be overstressed at a time when the nuclear energy programme is being reappraised, due to the relatively unforeseen abundance of conventional energy requiring assessment of the economics of all types of power reactors. Such a check would seem to indicate the necessity for further investment in advanced development and research by the Government and industry.

The computer is a powerful sophisticated tool of many forms and uses. At this time it assists in clarifying and presenting data which increases the thinking power of persons able to use it adequately. In time it may think itself. Its justification is economic and all discussions of computer use should be in terms of economics and should not be governed by fashion nor mental sloth.

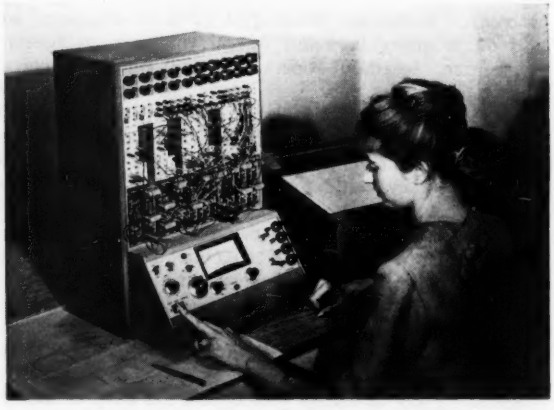


Fig. 2.—Fully transistorised all-electronic Pace TR-10 computer recently introduced in the U.K. These basic elements are suitable for many on-line and simulator applications.

Radiation and Electronic Design

By Dr. P. BARRATT, M.A., Ph.D.
(*Pye, Ltd., Cambridge*)

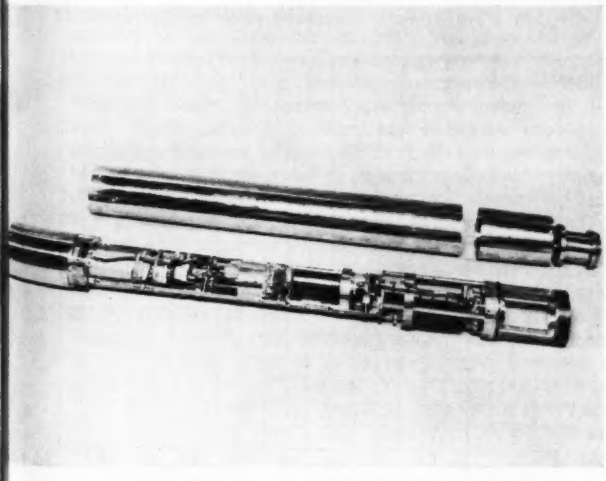
Electronic equipment—such as a TV camera intended for examining a fuel channel—is subjected to severe radiation in an operating reactor. The author's company have made an evaluation of the type of damage that may be encountered and the materials that must be selected to minimize the effects of radiation.

Standard television chain suitable for use in low level radiation fields. Left to right: camera, 14 in. precision picture monitor, control panel, camera control unit.

THE field of radiation damage in materials is very complex, and many aspects are still obscure. Work at Pye has been primarily concerned with the probability of damage to in-pile TV equipment—in particular, of course, the likelihood of damage to components—and the evolution of techniques which would minimize that damage. Applications of television equipment in which radiation is significant are numerous and have already been reviewed[1].

Radiation Damage

As the interactions of radiation with matter depend upon the type of radiation, the design procedure is considerably influenced by the subsequent use of the equipment. Hot cells are characterized by both gamma and beta (alpha particle ranges are usually too small for their effects to be important), while operational reactors subject equipment to fast and thermal neutrons, gamma, beta, and fission fragments. In general, as beta and fission fragments are easily stopped, their effects are superficial; the significant radiations are neutrons and gamma photons. An excellent general survey of radiation damage has already been published[2], together with detailed theoretical discussions[3].



A television camera for the inspection of shut-down reactors. This type can withstand gamma radiation dose rates of 10^6 r/h.

The primary effect of gamma irradiation is ionization; the photons interact with electrons which gain sufficient energy to leave their atoms and ionize other atoms. Neutrons also produce ionization, by "knock-on" nuclei, etc. The dependence of many chemical and physical properties upon the electron states is well known: chemical bonds, electrical conductivity, optical properties, and so on. In metals, the atoms are effectively ionized, so that there are negligible changes in resistivity. Semiconductors, on the other hand, rely on the great sensitivity of electron (or hole) concentration to various factors, and the effects of irradiation are catastrophic in most instances.

Neutrons not only disturb the electronic structure of materials, but also cause important effects on the atomic and molecular scales. Thermal neutrons may interact with the original nuclei to produce different, and perhaps radioactive, species, i.e. impurities are introduced. More important, a fast neutron has sufficient energy to dislodge an atom from its place in the orderly lattice. The regularity of the lattice has a great effect upon many properties, particularly mechanical. In addition to these effects, thermal heating results from radiation absorption.

The above may be termed primary effects, to distinguish them from the secondary effects which may, however, be the ultimate cause of a component's failure. These are particularly marked with organic materials. Ionization leads to disruption of chemical bonds, leaving free radicals which may recombine in different ways. Gas evolution may result, or materials in contact with the susceptible compound be attacked by corrosive products.

Some radiation damage is permanent, some persists only during irradiation. For instance, the leakage current of capacitors usually increases during irradiation, the magnitude being dependent upon the radiation level, and returns to its original value on removal from the field. This is a typical "rate effect" (e.g. Figs. 2 and 3). On the other hand, the changes in optical absorption properties of a glass, probably due in part to the forcing of atoms to positions of unstable equilibrium in the lattice, remain after irradiation has ceased. Here we have an "integrated-dose

TABLE 1
Selection of Materials for Minimum Effect upon Reactivity
Total neutron absorption cross-sections in barns
(From Ref. 4)

Element	Cross-section
Cadmium	2550
Boron	769
Iridium	430
Gold	98
Silver	62
Cobalt	37
Chlorine	31.6
Tantalum	21.3
Tungsten	19.2
Manganese	13.2
Platinum	8.1
Bromine	6.6
Titanium	5.6
Vanadium	5.1
Nickel	4.6
Copper	3.69
Iron	2.53
Zinc	1.06
Sodium	0.505
Hydrogen	0.33
Aluminium	0.23
Silicon	0.13
Magnesium	0.063
Oxygen	<0.0002

effect." In this particular case, as with many others, heating of the glass will anneal out some of the damage as the atoms receive sufficient thermal energy to return to stable lattice positions.

Where the implications of a given situation are to be assessed reasonably rapidly, it is usually preferable to express radiation damage effects in terms of the associated particle flux, or total particle dose, with the important qualification that the energy spectrum must also be specified.

Design Aims

In the case of in-pile television cameras, the conditions to be satisfied are:—

(i) The equipment must continue to function satisfactorily despite the ambient conditions.

(ii) The effects of the equipment upon reactor operation must be negligible.

(iii) The level of activity produced by neutron bombardment should be sufficiently low, and/or decay sufficiently rapidly, to permit subsequent handling and maintenance.

The second point implies the selection of materials with neutron-absorption cross-sections which are as low as possible. Table 1 shows that the variations in cross-section from element to element are such that significant improvements in the overall neutron absorption cross-section of the equipment can frequently be made if the correct material is chosen. In this context, undesirable chemical effects should be mentioned. No materials should be exposed to the reactor which, in their normal or irradiated states, can enter into chemical reaction with coolant, fuel, etc. This is most easily accomplished by totally enclosing the equipment within a casing of compatible metal.

The third restriction requires some definition of the mode of use of the equipment. There is no need to emphasize that, for a given neutron dose, different elements will become active to differing degrees, and these activities will probably decay with widely varying rates. Table 2 illustrates the effect of cooling time upon the relative activities of equal masses of a number of elements. Also, the health hazard associated with a particular decay depends upon the energy of the emitted radiation. The most significant time period is generally that between removal from the neutron field and the time at which close physical approach to the equipment is necessary. The irradiation period and flux level are also important factors. In most cases, the choice lies between two or three elements. For the general case, the concept of a "cross-over point" has been found valuable. This is the time, measured from cessation of irradiation, after which equal volumes or equal masses of two elements have the same activity. If the desired handling time is before the cross-over point, one element is used, times beyond the cross-over point require the second element.

On an equal-mass basis, the cross-over point, T_c, for two elements, x and y, is given by:

$$T_c = \frac{1.44\ t_x t_y}{t_x - t_y}\left\{ ln(A_x/\sigma_x) - ln(A_y/\sigma_y) + ln\left(\frac{1-exp(-0.69T_i/T_y)}{1-exp(-0.69T_i/t_x)}\right)\right\} \quad \text{Eq. 1.}$$

where $t_{x,\,y}$ are half-lives of neutron-produced activities,
$\sigma_{x,\,y}$ are activation cross-sections for parent nuclei,
$A_{x,\,y}$ are the atomic weights of the parent nuclei,
T_i is the duration of the irradiation.

Tabulation of the quantities $ln\ (A/\sigma)$ considerably simplifies the calculations.

If $T_i >> t_{x,\,y}$

$$T_c \triangleq \frac{1.44\ t_x t_y}{t_x - t_y}\left\{ ln(A_x/\sigma_x) - ln(A_y/\sigma_y)\right\} \quad \text{Eq. 2.}$$

If $T_i << t_{x,\,y}$

$$T_c \triangleq \frac{1.44.t_x t_y}{t_x - t_y}\left\{ ln(A_x/\sigma_x) - ln(A_y/\sigma_y) + ln(t_x/t_y)\right\} \quad \text{Eq. 3.}$$

It can be shown that Eq. 1 does not show any maxima or minima in T_c as T_i varies, hence Eqs. 2 and 3 represent the maximum and minimum values of T_c for any irradiation period. Note that these equations assume only one significantly active nuclide is produced in each element. When several active nuclides are produced, the cross-over point is more easily found graphically.

Susceptibility to Radiation Damage

The behaviour of different types of materials can be briefly summarized:

Metals. Very resistant to radiation damage both as regards mechanical and electrical properties. Important effects are induced activity and neutron absorption.

Inorganic Compounds. Negligible changes in mechanical properties; tendency for electrical resistivity to decrease; generally resistant to radiation damage.

Organic Compounds. Generally poor to fair resistance

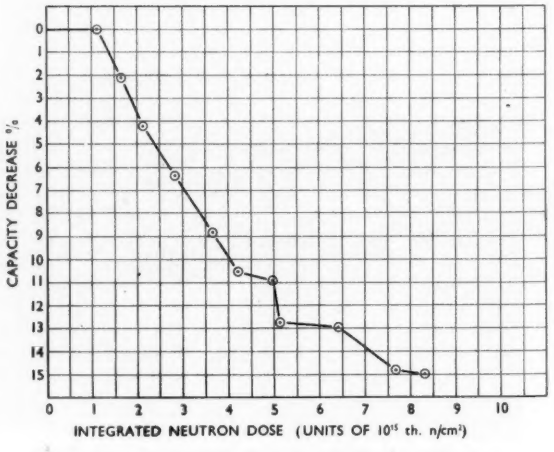


Fig. 1.—Variation of capacity of ceramic capacitor with thermal neutron dose[17].

to damage. Mechanical failure usually occurs before any electrical changes are significant.

Semiconductors. Electrical properties affected drastically before any mechanical changes are significant.

Component Layout

It is only possible to touch upon this topic but the discussion above shows that a number of factors must influence the way in which the components are assembled. Plastics should not be relied upon for mechanical support; as insulators, they become far less reliable, hence wiring should not pass conductors which are at considerably different potentials. The whole assembly is to operate in an ionized atmosphere, and hence gaps may no longer constitute adequate insulation. The re-appearance of absorbed radiation as heat demands correspondingly greater freedom for the atmosphere to circulate.

All in all, the picture which emerges is of electronic units which contain the minimum practicable quantities of components and structural material, all carefully selected, with rigid, well-spaced, wiring, and the components adequately separated. Separation has the added advantage that if corrosive materials should be liberated the effects on other components will be minimized.

The Behaviour of Electronic Components

Data on specific component types is scattered throughout the literature; the more important characteristics are summarized below. Most of the effects have been observed in experiments at Cambridge, but it is important to emphasize that minor changes in composition, e.g. from manufacturer to manufacturer, may produce significant changes in behaviour under irradiation. The references cited have been limited to those which contain the greatest amount of information. Table 3 gives the general picture.

Capacitors. Mica capacitors generally show negligible capacity changes by 10^{14} nvt[5] but some show 15% increases by 4×10^{17} nvt[6]. Ceramic types show approximately 1% decreases by 10^{14} nvt, with dissipation factor decreases of 0.01 to 0.1%[5].

Fig. 1 shows the variation of capacity with dose for a ceramic capacitor. Some give −12% integrated effect by 10^{18} nvt, with a rate effect of -6% at 7×10^{11} n/cm² sec[6]. Glass capacitors show typical decreases of 0.01% and 0.5% in dissipation factor and capacity, respectively[5]. Tantalum capacitors are reported to exhibit increases in capacity of the order of 1%, with negligible change in leakage current[5]. Boron-containing electrolytic capacitors fail by 10^{17} nvt[6], and piercing is suggested[7]. Oil-filled capacitors suffer enlargement due to gas leakage by 10^{18} nvt[6]. Some paper capacitors are noted as showing a maximum decrease in capacity of 12% (integrated effect) with a subsequent increase in capacity with dose[6]. Failure of the plastic casing is mentioned by one source[7].

Fig. 2 shows the variation of leakage current of an impregnated capacitor with flux level.

Resistors. Wire wound resistors are probably the most satisfactory[6, 7, 8]; metal film types also withstand radiation well[9]. Carbon resistors seem rather more susceptible, although the effects are generally small. Carbon resistors in the 100 ohm range show integrated dose decreases of from 0 to 6% for 10^{18} thermal nvt $+5\times10^{15}$ fast nvt $+10^{18}$ gamma/cm² at 50°C. Megohm carbon resistors have been found which give a rate effect decrease of 8% with fluxes of 10^{13} th.n/cm² sec $+10^{9}$ f.n/cm² sec $+2\times10^{12}$ gamma/cm² sec [6]. In one instance a 99% decrease in resistance was noted[7].

Valves, Television tubes, etc. Many types of valve suffer no serious damage with doses of 10^{18} nvt, although a few

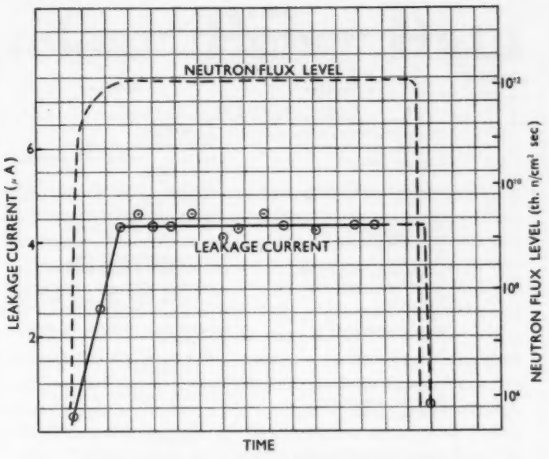


Fig. 2.—Variation of leakage current through impregnated capacitor with neutron flux[17].

types fail below 10^{17} nvt and Image Orthicons and tubes of the Vidicon type suffer glass darkening[8]. The ionization produced in thyratrons leads to false firing[9]; ballast tubes, and the heaters of all types of valve appear satisfactory. The resistivity of tungsten increases by approximately 5% after 10^{20} nvt[10]. Maximum irradiation for 3,000 hr in the CP-5 reactor shattered the envelopes of most tubes tested[8]. Our work has not shown any changes in the resistivity of tungsten filaments for doses up to 10^{16} nvt.

Quartz crystals. Frequency characteristics appear to be unchanged[7], but pronounced discoloration may occur[8].

Transformers. No changes in properties found[7] but, at high doses, insulation damage must obviously be taken into account.

Dry cells. No significant changes in life are observed but use as bias voltage sources is precluded by voltage changes during irradiation, e.g. −20% to +12%[7].

Semiconductors. A dose of 3×10^{14} nvt is sufficient to gives changes in forward voltage drop of +250% in silicon and 10 to 20% in germanium. Leakage currents may change by 100 to 1,000%. Selenium is comparatively unaffected[5]. N-type germanium can change to p-type[11] and may also tend to become ohmic[9]. Some silicon types have been found satisfactory[6]. Changes of 25db in tranistor noise level are given by 2×10^{6}r/h gamma dose rates. For descriptions of damage mechanisms and

TABLE 2
Effect of 14-day "cooling" period upon induced radioactivity
(6-day irradiation: 10^{11} n/cm² sec)

	Removal from pile	After 14 days
High Activity	Iridium	Gold
	Gold	Iridium
	Manganese	Tantalum
	Bromine	Cobalt
	Vanadium	Chromium
	Tungsten	Chlorine
	Copper	Silver
	Sodium	Tungsten
	Aluminium	Cadmium
	Tantalum	Zinc
	Chlorine	Platinum
	Platinum	Bromine
	Zinc	Iron
	Cadmium	Titanium
	Cobalt	Nickel
	Chromium	Sodium
	Nickel	Copper
	Titanium	Hydrogen
	Magnesium	Oxygen
	Silver	Magnesium
	Silicon	Silicon
	Iron	Manganese
	Oxygen	Vanadium
Low Activity	Hydrogen	Aluminium

TABLE 3

Radiation Effects upon Electronic Components

Integrated Dose n/cm^{-2}	Component	Behaviour
10^{19}	Wire-wound resistors	Satisfactory.
	Ceramic capacitors	10% capacity decrease.
10^{18}	Carbon resistors	Usually resistance decrease 1—10%.
	Oil-filled capacitors	Serious swelling and gas evolution.
	Valves	Some fail—become soft.
	Mica capacitors	16% capacity increase.
10^{17}	Boron electrolytic capacitors ..	Failure.
	Valve heaters	No resistance changes.
	Electrolytic capacitors	Increase in power factor.
	Tantalum capacitors	Satisfactory.
10^{16}	Dry cells	Considerable voltage and resistance changes.
	Plastic insulation	Significant changes in resistivity.
10^{15}	TV tubes	Increase in dark current, glass darkening.
	Tantalum capacitors	Few % capacity increase.
	Ceramic capacitors	Few % capacity decrease.
10^{14}	Potting resins	Significant changes in power factor and dielectric strength.
	Germanium transistors ..	Loss of amplification.
	Silicon semiconductors ..	100% increase in forward voltage drop.
10^{13}	Germanium semiconductors ..	10% increase in forward voltage drop.

a bibliography Ref. 3 is suggested. Not all the effects are permanent, although some persist (e.g. Ref. 13).

Insulated wiring. No significant changes occur in the conductors themselves, but the insulation resistance may fall by as much as 1,000×[9]. Decreases of 10× and 35× are quoted for PVC and polythene, respectively[6], the tendency for PVC to evolve chlorine should be remembered. Suggested maximum doses for some plastics have also been published[4].

Fig. 3 illustrates the dependence of resistance upon flux level for a plastic insulant.

Glasses. It is usually necessary to employ stabilized glasses since the discolouring of normal optical glass can become prohibitive. The subject is very complex and glasses vary considerably in their behaviour. Changes in optical properties may occur[5, 14].

Lubricants. The various manufacturers are able to supply a great deal of information on the radiation resistance of their products[15, 16].

General remarks. A great many types of component have not been discussed but their behaviour can be estimated by considering their construction: coils will be as good as the former and the insulation; microswitches will depend upon the stability of the body material; filament lamps will behave similarly to valve heaters.

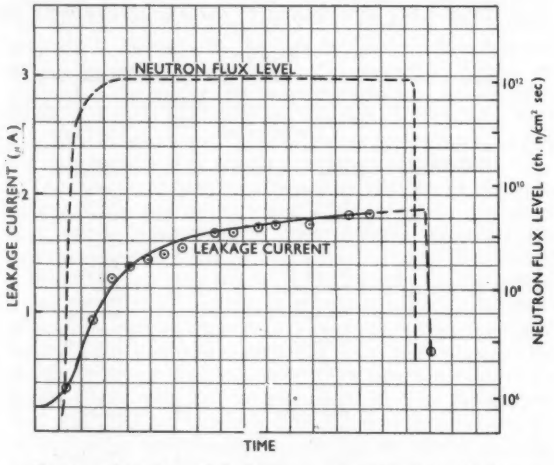


Fig. 3.—Variation of leakage current through plastics insulation with neutron flux[17].

Experimental Results

The principles outlined above have been tested by designing and building electronic units for in-pile irradiation. For tests such as these to be of any value, it is obvious that far more data must be recorded than can be presented in a short paper; accordingly, only the general results will be given.

The major aim was to study the behaviour of experimental television systems at high neutron flux levels, with subsidiary measurements of the changes in properties, during irradiation, of a number of components and materials.

The maximum flux levels used were slightly greater than 10^{12} thermal neutrons cm^2 sec, with the fast neutron fluxes approximately one order of magnitude less, and gamma dose rates in the region of 10^6 r/h. Integrated thermal neutron doses of 10^{16} cm^2 were reached.

Under these conditions, it has been shown possible to use a closed-circuit television system for a period of at least two hours. Some degradation in picture quality is observed, attributable to a number of causes which are still being studied theoretically. The experimental cameras included their own test cards and lighting systems.

The head amplifier and cathode follower assemblies showed no changes in performance during irradiation, and subsequent detailed analysis, when they had cooled sufficiently, confirmed the resistance of their components to radiation damage.

The effects of the equipment upon reactor operation were negligible and, most important from the practical viewpoint, the choice of materials resulted in equipment which could be handled with negligible safety precautions after cooling periods of only two or three weeks.

Conclusions

The theoretical and experimental work has demonstrated that high level radiation fields do not prohibit the use of complex electronic equipment so long as the equipment is properly designed, and a life of hundreds of hours can be anticipated. Furthermore, the units are not necessarily expendable and maintenance can be envisaged. This is a finding which should be of considerable interest to the designers of reactors and installations for handling highly active materials.

ACKNOWLEDGMENTS

The author is a member of a team which covers all the aspects of this work and the contributions of a number of persons are hereby acknowledged: Mr. G. B. F. Goff of Cathodeon, Ltd., for television tube design; Mr. I. M. Waters and his electronic design group; Mr. D. Jackson and Mr. A. Diehl for mechanical design; Mr. D. Pollard, for part of the theoretical work; Mr. V. B. Hessen and the directors of Pye, Ltd. for encouragement, and permission to publish this paper. In addition, special mention must be made of the personnel of AERE, Harwell, whose assistance during the experiments was invaluable.

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The Recording of Nuclear Pulse Data

By P. E. CAVANAGH, Ph.D.
(*U.K. AERE, Harwell*).

THERE are a number of pressures nowadays which force the nuclear physicist, in particular, to determine the optimum way in which he can use his experimental running time. In a fast-moving field he not only has to take account of the competition from other laboratories, but also from his own colleagues who wish to use the same experimental facilities, such as accelerating machines and pulse analysing equipment. Ideally, he should aim at extracting the maximum possible information from a given experimental situation. We must consider what form this information is likely to take.

The occurrence of well-defined energy levels in nuclei has led to a great emphasis in the measurement of the energies and energy spectra of nuclear particles. These measurements have been revolutionized during the past 10 years by the introduction of particle detectors, such as the scintillation spectrometer, all of which ultimately produce a pulse of electric charge, of amplitude dependent on the particle energy. For charged particles which are completely stopped in the detector the output pulse will be a simple function, in many cases a linear function, of the energy, so that the energy spectrum is determined by a measurement of the pulse amplitude distribution. With neutrons, however, the process of energy loss is different, and other techniques have been developed for determining their energy spectra. The most important utilizes a pulsed source of neutrons, and the time of flight of the neutrons over a fixed path is measured. Scintillators are used simply as very efficient detectors for neutrons, which also give a well-defined signal to mark their time of arrival. For neutrons in the resonance region, flight times may be as long as milliseconds, and it is usual to determine them by counting the number of pulses produced by a standard oscillator during the time interval between emission and detection.

Pulse Analysers

In one form of pulse analyser the charge pulse also is converted into a train of pulses, in number proportional to the magnitude of the charge; finally, both neutron and charged particle energies may be expressed as the number of pulses in a pulse train. The unit of energy represented by each, which may be referred to as the channel width, in general requires to be chosen so that it has no serious effect on the energy resolution of the detector. For scintillators recording charged particles, a few hundred channels suffice for the entire energy range. For slow neutron time-of-flight measurements the resolution may be much higher, and even a few thousand channels may be inadequate.

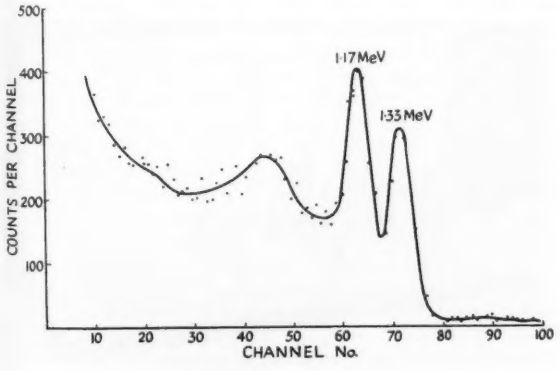

Fig. 1.—The recorded sodium iodide scintillation spectrum of γ-rays from Co^{60}.

The determination of any given particle energy is then reduced to the simple operation of passing the appropriate pulse train into a scaler. Most experiments, however, will involve the measurement of the energies of a great many particles, perhaps many millions, which will require the counting and recording of the number of detector events which fall within each individual channel. This necessitates a storage system, which may be similar to the ones employed by computers. The contents of all channels may be stored, together with a routing system, so that when a detector event falls within a given channel the content of the appropriate store is increased by one unit. At the end of the experiment the contents of the store must be available for printing out or transfer on to punched cards or some other computer input medium.

This defines the essential constituents of a pulse analyser. For a capacity in excess of a hundred channels it is necessarily a very complicated and expensive piece of electronic equipment. One thousand channels represents the limit of what is at present available. In considering the use of such equipment in an experiment we also have to take into account its serviceability, which naturally decreases with increase in complication, and its utilization. As in life, so in physics, one rarely gets something for nothing, and the employment of higher resolution is in general accompanied by a lower counting rate, not only per channel, but also integrated over the entire spectrum. This is well illustrated in low-energy neutron spectrometry where the integrated counting rate may fall to a few per second, and a thousand-channel analyser will be employed for long periods at only about a hundredth of the full rate which could be accepted.

Correlated Pulse Data

So far each event we have considered is concerned with the determination of just one particle energy, and already we have reached the practical limit imposed by the analysing equipment in approaching the ideal of extracting all the available information. But this is just the simplest type of event we wish to study. There are many processes in nuclear physics in which two or more particles are emitted within a very short time interval, for example, successive γ-ray emission following β-decay. There are a number of instances where two pieces of information may be obtained from a single event. For example, the capture of resonance neutrons results in γ-ray emission within a very short time interval. The detection of the γ-ray with, say, a sodium iodide scintillation spectrometer not only provides information on the γ-ray energy but also a timing signal, from which the time of flight, and hence the energy of the captured neutron, may be determined. In the latter instance, if a thousand channels are adequate for the neutron spectrum, for each of these channels we require a γ-ray spectrum. If a hundred channels is sufficient for

each γ-ray spectrum, then the analyser will have to have a capacity of a hundred thousand channels! Such an analyser is at present completely impracticable. The best that can be done, using conventional techniques, is to select a range of flight times which corresponds to a particular resonance peak in the neutron spectrum and to measure the corresponding γ-ray spectrum. The experiment must be repeated for every region of interest in the neutron spectrum. This clearly represents a great waste of accelerator running time, and the low counting rates make this experiment verge on the impracticable. This is true also of many other experiments, in some of which as many as four or five correlated quantities may be involved instead of the two we have discussed so far.

Data Recording

Obviously a different approach to the technique of experiment is required to circumvent the limitations imposed by the pulse analysing equipment. The one method by which this might be done appears to be to divorce the analysis of the data from the actual performance of the experiment. This necessitates the introduction of an intermediate stage, in which the pulse data are recorded as the experiment proceeds, in such a way as to preserve the correlations between the various detector outputs. The idea of recording pulse data is not a new one. Earlier methods of doing so, however, did not lend themselves to easy analysis of the record. They mostly involved visual measurements on a photographic record, which, even with some degree of mechanization, are extremely tedious, and may take a time greatly in excess of the original experiment. What is required is a method of recording which permits recorded pulse data to be fed directly into a conventional pulse analyser. It should be possible to present the recorded data to the analyser, a process which will be referred to as playback, a large number of times without deterioration. This is necessary for correlated data where, as we have seen, one pulse spectrum must be analysed repeatedly, each time varying the data selected for analysis by choosing a different range of pulse amplitudes of the correlated pulse. Finally, to complete the list of desirables, in order to prevent the analysis of correlated data greatly exceeding in time that for the experiment, and also to make optimum use of the analyser, it should be possible to speed up the record, as desired, on playback.

Magnetic Recording

The use of magnetic tape for recording nuclear pulses was first proposed by Cavanagh, Coleman and Turner[1]. In a subsequent development by Cavanagh and Boyce[2] the method which was explored employed one of the forms of analogue recording, that of amplitude modulation of the tape magnetization. Audio bandwidths may at first sight seem inappropriate to the recording of nuclear pulses with rise times less than a microsecond, but the only limitation is in the maximum pulse rate which may be recorded, to about 5 kp/sec for a tape speed of 15 in./sec. The rise time of the playback pulse is suitable for many conventional pulse analysers. The employment of analogue recording, however, immediately raises the question of fidelity. Fortunately the use of supersonic bias to prevent harmonic distortion in audio recording also ensures that the amplitude response is linear. A completely unknown characteristic was the pulse amplitude resolution of the recording/playback process. A number of effects, such as tape noise, variations in tape transport speed, etc., introduce variations in response, so that pulses initially all of the same amplitude will, on playback, be distributed in amplitude. This usually takes the form of a Gaussian

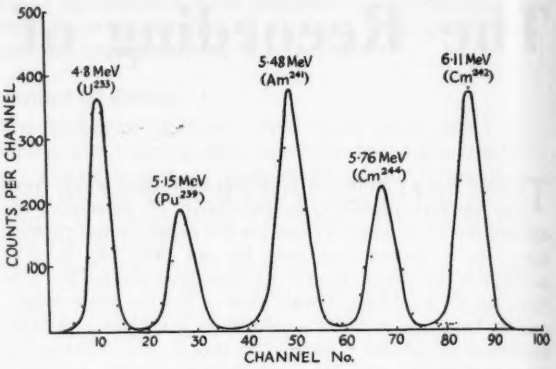

Fig. 2.—The recorded gridded ion chamber spectrum of a mixed α-particle source, using a cut-off amplifier to limit the energy range.

distribution. The use of a good instrumentation tape with quite a moderately priced tape deck will result in a resolution, defined as the relative full width at half height of the amplitude distribution, of about 2%. To assess the effect of this on the resolution finally obtained it must be compounded vectorially with the detector resolution itself. Thus a detector resolution of 5% will become 5.4% on playback. This method of recording is then suitable for a great many low-energy applications, such as the scintillation spectrometry of β-ray and γ-rays, where the detector resolution is not very high (see Fig. 1). It may even be applied to high resolution detectors, such as a gridded ion-chamber for α-particles, provided that the range of energies of interest is small (see Fig. 2).

The other recording criteria which were advanced are also satisfied. Pulses may be recorded with the tape moving extremely slowly, providing that they are suitably lengthened. Playback is then effected at the normal tape speed. Speed-up factors of up to a thousand to one have been employed, compressing the analysis of a week's experiment into a few minutes. This is the technique, of course, which has been exploited subsequently so successfully for earth satellite transmissions.

The application to correlated pulse data is met by multi-track recording. Pulses which satisfy the correlation conditions are fed, one output to each track, to a multi-track recording head which records them on parallel tracks along the tape. The number of tracks permissible for a given tape width is, however, limited by the dependence of the pulse amplitude resolution on track width. On playback there is no difficulty in picking out the pulses which

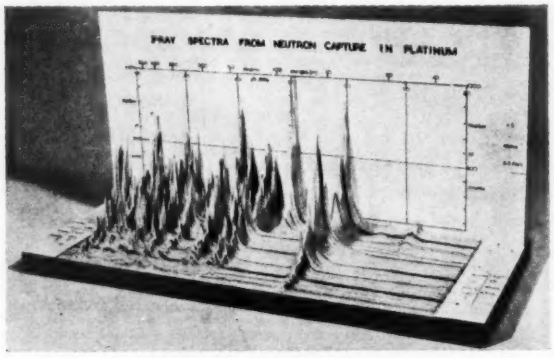

Fig. 3.—An example of recorded correlated data[4]. (Photo by permission of *Nuclear Physics*).

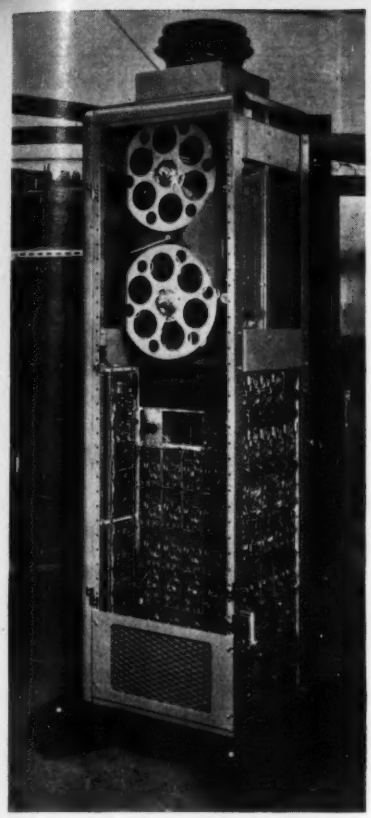

Fig. 4.—Magnetic tape recording equipment manufactured by E.M.I.

constitute the correlation event, while on repeated playback the pulse amplitudes remain the same within about 1%.

We have, therefore, a powerful technique for the extraction of complex pulse data from an experiment, using the minimum of equipment. A two-track recorder used in a correlation experiment is equivalent in this respect to an analyser having about ten thousand channels! That the technique has not yet been fully exploited in this form is partly due to the fact that the main urge for the use of recording techniques has so far come from neutron spectrometry, for which the accuracy of analogue recording is insufficient.

Digital Recording

It is desirable to keep the electronics involved in an experiment, and the means of recording the data, as simple as possible. From this viewpoint analogue recording may be preferred. Where, however, this does not provide adequate accuracy, and where in addition the data is initially available in digital form, as in slow neutron spectrometry, then the case for digital recording is overwhelming. In this form of recording the channel number is expressed as a number in the binary code, the elements of which are recorded as digital pulses. One of the disadvantages of digital recording stems from the fact that, even with the closer packing of pulses which can be used, a quantity expressed digitally takes considerably more tape space than one expressed as an analogue. In order to retain a reasonable speed-up factor on playback it has been found necessary to use higher tape speeds, of the order of 100 in./sec. In addition, a number of tracks may have to be used for recording a single quantity instead of just one.

In one system developed at Harwell[3] there are 16 tracks on 1-in.-wide tape. Fifteen record digital pulses. In a typical arrangement 10 of the tracks might be in use, each one recording an element of the 10 bit binary number which corresponds to the neutron time of flight. The remaining five tracks could be used, say, for recording the correlated capture γ-ray spectrum (Fig. 3). Of course, where the quantity is initially available in analogue form, as is the γ-ray energy, it is necessary to interpose an analogue/digital converter before the recorder (Fig. 4).

Digital recording is considerably more expensive than analogue, and has the additional disadvantage of requiring more complicated equipment to be in use in the actual experiment. To compensate for this, much higher resolutions are available than from the straightforward analogue system. Moreover, there are important advantages in the analysis of complex correlation data.

Analysis

There are no particular problems involved in the analysis of straightforward energy or time spectra, as to make recording worth while it must be possible to speed up the record on playback. Correlated data, on the other hand, may involve the use of a great deal of analyser time. Consideration of the efficient use of analysers favours digital recording, because the several correlated quantities, when recorded digitally, may be regarded as consisting together of a single binary quantity. If this is larger than the number of channels available in the analyser then there must be repeated playback. The binary number must then be broken up into two parts, one of which is fed into the analyser and chosen to fill its capacity. The second part is used to vary the selection conditions when playback is repeated. Pulses recorded analogue-wise cannot be treated in this fashion, and this constitutes a major disadvantage for this system. The merging together of a number of variables in the digital playback, however, necessitates care in the interpretation of the analysis.

A further improvement in analyser utilization can be effected by re-recording. The data, on playback with given selection conditions, instead of being passed direct to the analyser, may be repacked on to a slowly moving tape. Each combination of the selection conditions results in the recording of a further block of data on the second tape. The great virtue of this re-ordering process is that the data is then in a form to be passed into the analyser just once for a complete analysis!

Complete analysis is rather a mechanical process, and is frequently not necessary. Where selected analysis only is required conditions approach more nearly to performing a series of experiments with the recorded data.

Physicists are understandably reluctant to entrust their hard-won data to a complex processing system without adequate safeguards. So auxiliary analogue systems will be required, both when recording and on analysis, to give a visual check on the performance of the equipment.

The Future of Data Recording

As might be expected, the recording technique is being used principally at present in those applications which produce data of a rather uniform and routine nature, such as slow neutron spectrometry. In the wider field there must be considerable flexibility in recording and playback facilities. The enormous gain in data-gathering power provided by these techniques, where correlated events are studied, must eventually lead to their widespread use in this field also. Both analogue and digital systems will have their place.

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Beryllium Handling

at Lucas Heights

By G. L. HANNA, K. D. REEVE, and W. J. WRIGHT
(Australian AEC, Lucas Heights)

As part of a development programme on gas-cooled reactor systems the Australian AEC is investigating beryllium as a moderating material. Specially designed laboratories are being inaugurated at Lucas Heights. In view of the world-wide interest in the material and the problems that arise in handling it we present here a description of the new laboratories.

THE research programme of the Australian Atomic Energy Commission, centred at the Lucas Heights Research Establishment, near Sydney, is directed principally towards the development of a gas-cooled, thermal breeder reactor system. Moderating materials being actively considered are beryllium metal, beryllium oxide and graphite.

The initial stage of this programme has called for parallel irradiation and other testing of beryllium and beryllium oxide, and of dispersion type fuel element systems in which fissile and fertile material in suitable form (e.g. as intermetallics, oxides or carbides) is dispersed in the moderator. Fabrication facilities for beryllium and beryllium oxide are essential to this programme and an important phase in the planning of the Lucas Heights Establishment has been the design and construction of metallurgical laboratories for handling these highly toxic materials on a laboratory and pilot-plant scale.

Beryllium handling was commenced in March, 1959, in the temporary accommodation of a laboratory of 1,200 sq. ft floor area situated in the Chemistry-Chemical Engineering Building and, shortly afterwards, construction commenced of specially designed Beryllium Laboratories which will provide 3,350 sq. ft of laboratory floor space and 2,500 sq. ft of office and change room space. Equipping of these new laboratories began in March, 1960, but active commissioning is not expected to take place for several months.

In addition to the laboratories described in this text, a fabrication laboratory of 5,000 sq. ft. attached to the main metallurgical laboratories is equipped for the fabrication of a variety of nuclear metals including beryllium and enriched uranium.

Working Principles

In planning health precautions and handling procedures, the U.S.AEC recommendations for maximum permissible concentrations of beryllium in air were adopted, namely 2 $\mu g/m^3$ as a mean concentration over an eight-hour day, 25 $\mu g/m^3$ for instantaneous concentration peaks in the laboratory and 0.01 $\mu g/m^3$ in the neighbourhood of the plant.

American and British experience has shown that if adequate control measures are taken, air concentrations can be kept well below these levels. Control is achieved principally by confinement of hazardous operations, the provision of adequate ventilation—both general and localized—and by strict attention to laboratory hygiene and changing procedures. The minimum control measures necessary are fairly well established but differ in detail from laboratory to laboratory. The principles outlined above were formulated prior to equipping the Lucas Heights laboratory and these led to the adoption of the following machining methods for beryllium and beryllium oxide:

(1) High-speed machines in which the use of a coolant is necessary would be boxed to allow operation under completely enclosed conditions, and ventilated in accordance with (5) below.

(2) The lathe would be similarly enclosed to allow wet or dry turning (with wet turning preferred) and cylindrical grinding of beryllium oxide using a tool-post grinder. The attendant disadvantages of this type of enclosure for machining compared with other methods were accepted in view of the temporary nature of the installation.

(3) Drilling of beryllium metal would be carried out without a coolant in a ventilated box, with an additional local exhaust to remove fine dust.

BERYLLIUM LABORATORY: DESIGN CRITERIA

(1) Laboratory background ventilation providing at least 10 air changes per hour is necessary.

(2) All laboratory air extracted must pass through "absolute" filters before discharge to atmosphere.

(3) All staff working in the laboratory must be provided with a complete change of clothing and visitors with laboratory coats and overshoes.

(4) The handling of beryllium and its compounds in powder form should be carried out where possible under static conditions in some form of glove box.

(5) All operations involving powder or dust generation which cannot be carried out in glove boxes must be performed in ventilated boxes. A minimum face velocity of 120 ft/min across openings in such boxes is necessary.

(6) Cupboards in which contaminated articles (e.g. dies, machine tools, etc.) are stored should be ventilated, but not necessarily to the degree stated in (5).

(7) For operations in which powders are contained (e.g. within dies, steel sheaths of furnaces) and which are therefore not subject to the restrictions of (4) and (5) there should be a movable local exhaust outlet to provide a safeguard in case of leakage.

(8) Fireproof storage space is essential for all beryllium and other hazardous materials (e.g. uranium and thorium) in use in the laboratory.

Ventilation

In order to satisfy these requirements, three filter booster units fitted with pre- and absolute filters were installed between the laboratory and the exhaust duct of the building's main ventilation system. These units, one of 2,000 ft^3/min and two of 4,000 ft^3/min capacity, extract the laboratory air through six fume hoods and through the ventilated enclosures around equipment. The fume hoods are fitted with constant exhaust registers and, even when closed to their minimum opening, alone provide about 12 air changes per hour in the laboratory. The opening of fume hoods and handling boxes raises this figure markedly. For example, with two fume hoods fully open, the number of air changes rises to about 40 per hour. Details of the loads on the filter-booster units, and of the

Table 1

Details of ventilation openings, face velocities and demands on filter-booster units.

Booster Unit	Use	Opening	Face Velocity, ft/min	Extract, ft³/min
1	4 fume hoods ..	min. 1 ft²	135	540
		max. 4 ft²	135	2,160
	3 constant exhaust registers ..			1,155
	Metallographic polishing bench..	max. 7 in. × 8 in.	120	45
	Furnace exhaust ..	3 in. dia. flexible hose	1,000	50
2	Fume hood ..	3 ft 6 in. × 1 ft	300	1,050
	Constant exhaust register			400
3	Fume hood ..	3 ft. 6 in. × 1 ft	135	450
	Constant exhaust register			400
	Lathe enclosure ..	10 ft × 14 ft or 8 in. × 20 in.	500	1,000
	Pillar drill box ..	Two 6 in. dia. ports	400	160
	Diamond drill box..	9 in. dia. ports	500	200
	Surface grinder box	9 in. dia. ports	300	150
	Press exhaust ..	3 in. dia. flexible hose	4,000	200
	Lathe tool cupboard			100
	Die storage cupboard			15
	Drum handling box	28 in. × 24 in. or 10 in. × 10 in.	150 1,000	700

size of openings and face velocities across them, are given in Table 1.

When handling material in the open laboratory, local ventilation conditions can be supplemented with a portable, 50 ft³/min vacuum cleaner in which the bag has been replaced by an "absolute" filter. The exhaust from this can be fed through a hose into the booster extract system at any convenient point. The unit can be used for the preliminary cleaning of powder spills if such should occur.

Powder Handling

Both metal and oxide powders arrive at the laboratory in drums too large for convenient handling. The transfer of material to smaller containers is done in the drum handling glove box, which is ventilated from the rear through a 6 in. diameter flexible hose. Drums are admitted through a sliding perspex panel which forms the front wall and gloves fitted to the top face permit powders to be handled with the box fully closed. Small containers, when filled, are removed through a small, hinged side door after preliminary decontamination within the box. With all such enclosures particular care is necessary to avoid eddy currents which may spread contamination. The solution is generally to streamline the air flow, if necessary by reducing the velocity across the working face.

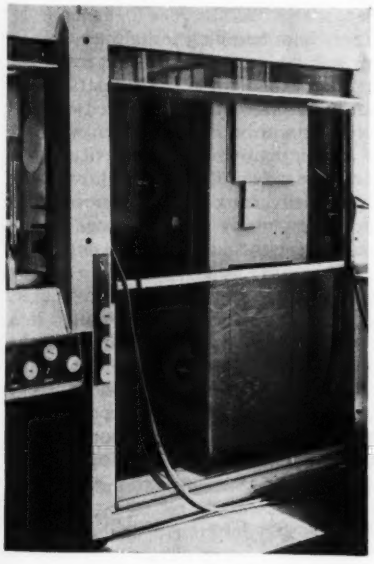

Fig. 1.—Muffle furnace for calcination of beryllium oxide. Note the proximity to a powder handling box which can just be seen in the adjacent fume hood.

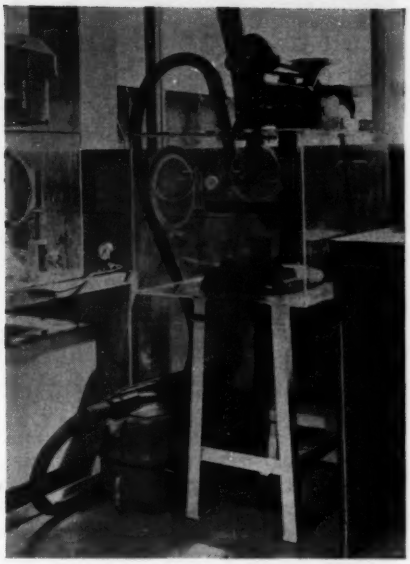

Fig. 2.—The pillar drill. The vacuum cleaner provides local exhaust when drilling.

Further powder handling is carried out in simple glove boxes which were designed to take advantage of existing fume hood space and ventilation. Whilst satisfying the principles enunciated earlier they avoid some of the restrictions of a standard glove box. Constructed from Perspex panels, they measure 3 ft 6 in. × 2 ft. 6 in. × 1 ft 6 in. A small door on the front panel provides access to the box but is not opened without first opening a sliding door on the top panel. The normal fume hood ventilation provides a flow of air over the face of the box at all times, and, when both doors are open, a flow through the box of about 150 ft/min. With both doors closed, powder can be handled under fully static conditions. Equipment is provided in the boxes to permit at least preliminary decontamination of all articles before they are withdrawn.

It should, perhaps, be emphasized that these boxes do not require such an elaborate housing as a fume hood designed for chemical work. In the new laboratories they will be housed in a simpler, free-standing enclosure giving the same ventilation conditions as the fume hoods give at present.

Calcination of small amounts of beryllium oxide is carried out in a muffle furnace housed in a full-length fume cupboard adjacent to one of the powder handling boxes. A hole cut in the fume hood wall and a door in the side of the handling box enable powder to be passed from box to furnace, and vice versa, without withdrawing it from the ventilated area of the fume hood. The enclosed furnace is shown in Fig. 1.

It was originally felt that fume hood conditions would be adequate for slip casting of beryllia but recently a modified powder handling box was installed for this operation. This box differs only in minor detail from those described above.

Metallographic Preparation

Polishing of metallographic specimens is carried out in a glove box with three sections. The three compartments, each lined with laminated plastic and fitted with Perspex slides, contain respectively wet papers, diamond laps and an automatic polishing machine. Final preparation by the polish-attack method can be carried out in a second automatic polishing machine in a nearby fume cupboard.

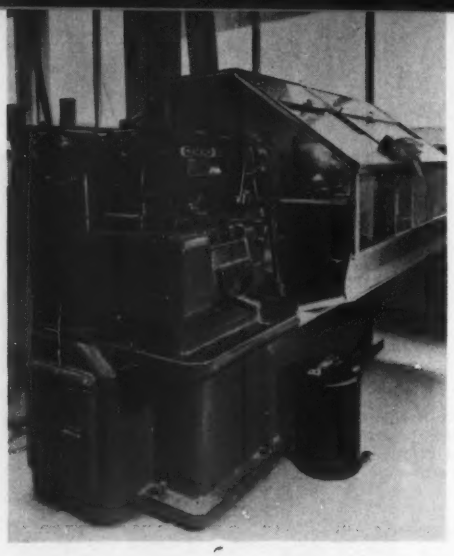

Fig. 3.—(Left) Lathe and its ventilated enclosure.

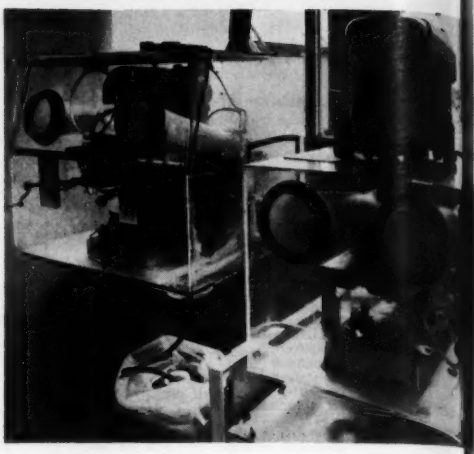

Fig. 4. — (Right) The enclosures about the surface grinder and diamond drill have been improved by fitting gloves to the operating faces.

Machining

The machines at present in use—a lathe, pillar drill, diamond drill, and surface grinder—are pictured with their enclosures as originally constructed in Figs. 3 and 4. Where possible, all components likely to require regular maintenance (e.g. motors, pumps, etc.) were not enclosed. This condition was achieved in all cases except the surface grinder where the result has not proved entirely satisfactory in practice.

In the course of operation it was decided that the fitting of gloves to the surface grinder and to the diamond drill (Fig. 4) would greatly reduce the danger of contamination spreading to the operators and, via their hands, to other parts of the laboratory. The operators have expressed a definite preference for the gloves as against the original hand ports.

The only machine operated without a coolant is the pillar drill. The local exhaust at the point of dust generation during drilling is provided by connecting the laboratory vacuum cleaner which can be seen in position in Fig. 2.

The lathe enclosure has proved quite satisfactory in preventing airborne contamination but it also suffers from the disadvantage that the interior becomes badly contaminated, with consequent danger of manual spread outside the box. The fitting of gloves was tried but did not help as accessibility was greatly reduced. One of the biggest disadvantages, however, is the limited access to the enclosed components and the consequent difficulty in operation. This, together with the high contamination within the box, may well mean that a change will be made to dry turning with local, high-velocity exhausts. A cylindrical grinder being installed in the new laboratories will eliminate the necessity of using the lathe in this capacity.

As indicated earlier, all operations where powder is contained are carried out in positions where local extract is available. A flexible 3 in. exhaust hose, provided near the hydraulic presses, can be brought into the immediate vicinity of dies in pressing and extrusion operations and a similar hose is provided at the furnace bench and can be used either to take the exhaust from vacuum pumps or to provide ventilation when unloading furnaces.

Changing Procedures and Laboratory Hygiene

Staff working in the laboratory are issued with a complete change of clothing daily and, in the laboratory, are required to wear a laboratory coat and overshoes. Other parts of the building, including the offices which are adjacent to the laboratory, may be visited on removing the latter garments at a barrier at the laboratory entrance.

A contamination clearance certificate must be obtained before articles can be freely removed from the laboratory and contaminated articles, e.g. beryllium specimens, are sealed into polythene bags before removal.

Each man must be medically approved before he may commence work on beryllium. Thereafter, routine chest X-rays, vital capacity tests and general medical examinations are given at regular intervals.

When the laboratory was commissioned, all operations were first performed under the strict supervision of the Health Physics Section and all persons present wore respirators. Once the operating procedures were shown to be satisfactory a routine service of daily air contamination checks and twice-weekly surface contamination checks were introduced. Air samples are taken with the same type of sampler as used by the U.K.AEA[1] and surface checks by smearing with small filter papers. A surface contamination tolerance level of 1 $\mu g/ft^2$ of removable beryllium has been adopted. This is a very conservative figure when compared to that of 25 $\mu g/ft^2$ which was recently quoted by American workers[2].

Air concentrations have been extremely low but surface contamination has been found occasionally to approach or slightly exceed 1 $\mu g/ft^2$. In general, however, the results have been satisfactory.

The issue of Contamination Clearance Certificates is also the responsibility of Health Physics Section.

The New Laboratories

It is intended that beryllium handling techniques used in the new laboratories will be essentially similar to those used in the temporary accommodation. The extra space will permit much more equipment to be installed but the fitting of ventilation to this will be in accordance with the principles enunciated earlier except where experience has shown modifications to be advisable. There are strong arguments in favour of converting to dry turning (and probably milling when introduced) and the move to the new laboratories would seem the ideal time to introduce the change.

Much less fume cupboard space will be available, however, and powder handling boxes will be installed in a specially constructed ventilated bench which will give the same ventilation conditions as obtained in the fume cupboard. Storage space with 550 sq. ft of floor space has been provided and will replace the two fireproof safes in use at present. Offices and Conference Room will be near the entrance to the building and will be outside the contamination area.

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Grenoble Plutonium Conference

THE 2nd International Conference on Plutonium Metallurgy was held at Grenoble from April 19-22; 43 papers from the U.K., U.S. and France were presented in four sessions on the physical properties of plutonium, plutonium alloys, plutonium ceramics and plutonium fuels, the major discussion on the last topic being concerned primarily with the prospects for future fast reactors.

PHYSICAL PROPERTIES

It was evident in the discussions on physical properties that much more information is now available from studies of the transformation kinetics of the various phases and from measurements of the low temperature properties such as electrical resistivity and specific heat. The origin of the negative volume coefficient of thermal expansion of the delta phase of plutonium metal has been a source of much interest since it was first reported in the unclassified literature in 1954. Theoretical treatments of the factors affecting the electronic contribution to the free energy of the system had shown that a negative volume coefficient of expansion is possible where the density of states at the Fermi surface changes sufficiently sharply with energy, particularly if this is associated with the existence of a large number of overlapping bands; a corollary of this is that the coefficient of thermal expansion of the delta phase will be strongly affected by alloying additions. U.K. measurements of the electrical resistivity and the thermo-electric power have now been obtained on various stabilized delta phase alloys, and although the experimental data are still very incomplete, progress towards a qualitative explanation of the main features has been made along the lines that there is a general tendency towards low or negative resistivity coefficients related to the high density of states at the Fermi surface with a possible additional overlap contribution in the case of the delta phase. The thermal expansion of binary delta phase alloys containing zinc, aluminium, cerium and zirconium has also been investigated and the results indicate that small amounts of these alloying additions to plutonium lead to an increase in the rate of the negative expansion of the delta phase. Further additions reverse this effect, the expansion becoming zero and then positive with increasing alloy content. Examination of the manner in which the expansion coefficient varies with the electron/atom ratio shows that the point at which the expansion is zero is primarily dependent on electron concentration, but is also dependent to a lesser extent on the metallic size of the solute atom. Attention has also been given to the factors influencing the retention of the delta phase at room temperature, and it has been found that only tri-and tetra-valent metals which have a favourable size factor are capable of exerting a stabilizing influence.

The preparation of plutonium metal was also included in this session, and there was a description of the Los Alamos work on the calcium reduction of plutonium halides. Methods and equipment used to prepare metal of $> 99\%$ purity with high yield from either plutonium trichloride or plutonium tetrafluoride were presented and the effects of process variables such as the reduction scale (from 1 to 500g plutonium), the use of iodine as a booster, the temperature-time cycle, the purity of the halide and the crucible properties on the product yield and purity were discussed. The preparation of high purity plutonium has also been investigated at Argonne by fused salt electrolysis with plutonium anodes containing 1,000-4,000 ppm of impurities. Hastelloy and Vycor cells with molybdenum and tantalum cathodes were used and satisfactory buttons were obtained by melting the electrolytic deposits under molten LiCl/KCl or NaCl/KCl. The subsequent metal contained only 65 ppm of total impurities as compared with best figure of 300 ppm impurities prepared by bomb reduction.

ALLOYS

In the alloys session new phase equilibria data on various systems were presented but the major discussion was concerned with ternary plutonium-uranium-molybdenum alloys. Molybdenum additions to uranium stabilize and strengthen the γ phase more than any other alloying addition; furthermore, uranium-molybdenum alloys containing 28 at.% molybdenum have good corrosion resistance and exceptional resistance to radiation damage compared with unalloyed uranium. If the fissile content of the fuel could be raised, therefore, such alloys are potential fast reactor fuels and hence the Pu-U-Mo system is receiving considerable attention at present. Constitution studies have been carried out to determine the extent of the γ uranium field and also the liquidus and solidus over the range of compositions from which possible fuels could be selected. On the basis of these results alloys were chosen which would be single phase γ at temperatures above 650°C and fabrication studies involving melting, casting and rolling have been carried out. As a general rule an increase in the plutonium content decreases the ductility of the ternary alloys, this effect being most marked in the case of alloys containing more than 15 at.% molybdenum; further work is necessary to determine the reasons for these changes in ductility because of their importance in fabrication behaviour. Some preliminary irradiation information was also presented in the discussion which indicated that the addition of plutonium to the U-Mo system may have a detrimental effect on the radiation stability.

CERAMICS

The papers on plutonium ceramics were mainly concerned with the PuO_2-UO_2 system. U.K. work on the development of a process for preparing dense uniform pellets of the mixed oxides was outlined. In this work, the concentration of PuO_2 was 1 mole % and sinterable powders were prepared by the continuous co-precipitation of ammonium diuranate and plutonium hydroxide. Subsequent sintering in hydrogen at 1550°C resulted in high bulk densities of 10.6 g/cc; it was concluded that PuO_2 when present in solid solution in UO_2 as produced in the co-precipitation process, tends to promote the sintering of UO_2 in hydrogen. In contrast, physical additions of PuO_2 in powder form reduce the sinterability of UO_2. U.S. and French work in this field also showed a preference for the co-precipitation route at low PuO_2 concentrations and a general pattern of the sintering behaviour of either co-precipitated PuO_2-UO_2 powders or mixed PuO_2-UO_2 powders appears to be emerging. There were large differences, however, between U.S. and U.K. results on the stability of PuO_2 and its ease of reduction when

PuO_2-UO_2 mixtures are sintered. The U.S. conclude that no reduction of PuO_2 occurs during heating in hydrogen at temperatures up to 1,600°C whereas U.K. work indicates that PuO_2 is relatively easily reduced at high temperatures to Pu_2O_3 and hence the extent of the PuO_2-UO_2 solid solution obtained from mixed powders appears to be dependent on the sintering atmosphere used. The discontinuities observed on thermal expansion curves of "PuO_2" also appear to be associated with this question of stability.

Irradiation data were presented by the U.S. on 11-in. long rods fabricated by vibratory compaction of PuO_2-UO_2 mixtures in Zircaloy tubes. In these particular experiments, the fuel had a low bulk density but it was stated that it was now possible to produce oxide with bulk densities of 88% theoretical by the vibration technique. The rods were irradiated in MTR and post-irradiation examination indicated that no dimensional changes had occurred, but there had been a relocation of the low density fuel due to sintering in the reactor. Other features noted were the formation of a central void and the appearance of a columnar grain structure after irradiation. A difference in the cracking occurring on irradiation was obtained between the rods containing PuO_2 and the control specimens enriched with uranium-235. The U^{235} oxide specimen was fragmented severely into small pieces, whereas the PuO_2 containing rods had large sintered sections which could be extracted from the sheath after cutting. In discussion the question arose of whether one used fuel elements prepared by integral techniques (either vibratory compaction or swaging of PuO_2-UO_2 powders) or whether one proceeded via the now established route for UO_2, namely cold pressing followed by sintering to high bulk densities followed by grinding. It may be that the answer is largely dependent on the type of reactor application envisaged; thus in the PWR case with a high external water pressure there appears to be a good case for vibratory compaction or swaging whereas in the gas cooled case as fission gas release from irradiated fuel should be kept to a minimum there appears to be a preference for the use of high bulk density sintered material.

Attention was also drawn to stoichiometry in the PuO_2-UO_2 system and its effect on fission gas release. It is now well established that the diffusion of fission gases from UO_2 containing excess oxygen is faster by several orders of magnitude than from UO_2. On this basis since PuO_2 can lose oxygen very readily it might be argued that the preferred fuel from the point of view of fission gas retention is the fully reduced Pu_2O_3-UO_2 solid solution and not PuO_2-UO_2 itself.

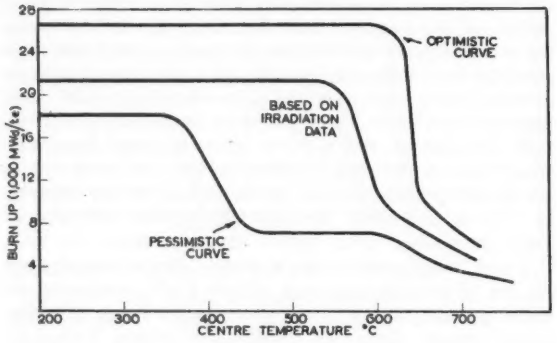


Fig. 1.—Burn up limitations of U-10 w/o Mo as a function of temperature.

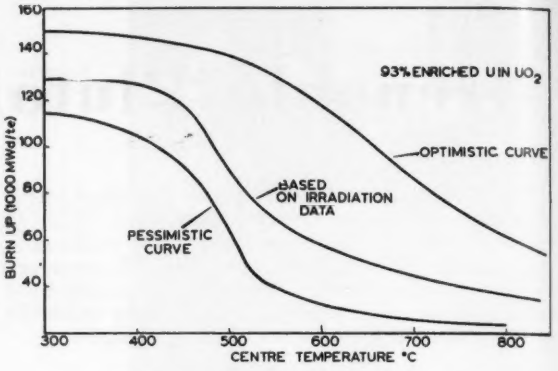


Fig. 2.—Burn up limitations of 30 w/o UO_2 or PuO_2 dispersed in stainless steel.

The U.S. paper on the plutonium-carbon system was also topical in view of the increased interest in carbide fuels. Here the main features were that PuC appears to exist as a phase, deficient in carbon (and not as the stoichiometric compound) and also melts peritectically at 1,650°C to give Pu_2C_3 plus liquid. It might be possible to utilize this liquid phase formation at high temperatures to aid densification when PuC-UC mixtures are sintered.

FUELS

In the final session which was devoted to nuclear fuels, many features of the science and technology discussed previously and their interaction with other factors such as economics and irradiation life, were presented. In the U.S. paper presented by A.P.D.A. the views on plutonium fuels for the next large fast breeder power reactors were given and it was indicated that a fast reactor incorporating a nominal extrapolation of present technology has an attractive economic potential, provided a satisfactory plutonium fuel element can be developed. The fissium pyrometallurgical approach being investigated by Argonne with EBR-2 and the molten Pu alloy systems being investigated by Los Alamos with the LAMPRE project are promising in the long term. It appears, however, that the next large fast breeder reactors to be built in the U.S.A. will be based on the fixed fuel technology developed for present fast reactors and depend on centralized processing facilities for the irradiated core and blanket. The advantages of fabricating a fully decontaminated material, particularly to the close tolerances required for fast reactor fuel elements, are important, and in addition the complexity of nuclear power operations now tends to favour separation of the major operations of the fuel cycle into highly specialized central plants serving many reactors. So far as the U.S. is concerned, therefore, the greatest immediate interest is in those fuel systems which incorporate solid transportable fuel elements which are amenable to conventional aqueous reprocessing techniques. In all economic evaluations of solid fuel fast reactors, the irradiation life of the fuel element is the most important variable to be considered. For the U-10 w/o Mo alloys considerable irradiation experience is available and the curves in Fig. 1 represent A.P.D.A.'s interpretation of this information. Here the centre curve represents a "normal" interpretation of the data, and the pessimistic curve a lower limit below which no failures have occurred. The optimistic curve represents the predicted maximum achievable with U-10 w/o Mo containing further minor alloying additions to obtain higher strengths. In Fig. 2 similar data is given

for cermets of oxide in stainless steel. The irradiation data on UO_2 clad in stainless steel (and it is assumed that the PuO_2-UO_2 solid solution behaves similarly) indicate that the burn-up limitations are a function only of fuel element design, the release of gaseous fission products being the only force that could cause swelling.

After these general considerations, ideas were presented on two studies related to plutonium fuel fast breeder reactors. The first incorporated improvements on the Fermi reactor and was designed for an output of 300 MW(e). It was a true breeder with a plutonium core and depleted uranium blanket. The reference fuel was the PuO_2-UO_2 solid solution, the core being approximately 36 in. high by 60 in. diameter; it consisted of 188 hexagonal core sub-assemblies each containing approximately 400 fuel pins. An interesting feature of this design was the provision of a fission product gas collection chamber which was an integral part of the fuel pin, but located above the upper axial blanket (i.e., outside the active region of the reactor). The current effort is devoted to the development of the conceptual design for a 150 MW(e) PFFBR. The PuO_2-UO_2 solid solution is again the preferred fuel material, but the actual design of this latter element is significantly different in that provision is made for the containment of the gases within the fuel element itself by cladding in a relatively strong stainless-steel tube.

It will be noted that from this assessment PuO_2-UO_2 is considered the most likely fuel for the next large fast reactors. However, more data is required on the fission gas release properties and particularly the relative merits of high versus low bulk density oxide in a strong can. In addition the possibility of fuel relocation within the element which occurs with low density oxide might give cause for concern particularly if it occurred longitudinally and in an unpredictable manner. The PuC-UC fuel has the obvious advantages of increased metal density and much higher thermal conductivity (which, being electronic, does not decrease appreciably with temperature). For similar ratings, therefore, the centre temperature is much lower than in the oxide case and the effects of bulk density might not be so critical in relation to fission gas release. A feature of the carbide which did not receive much attention at this Conference is that as it is readily wetted by liquid metals, there is the possibility of bonding the fuel to the can and so avoiding the effect of the "gap" on the overall thermal conductivity of the fuel element (appreciable in the oxide case). However, insufficient is known regarding the irradiation behaviour of PuC-UC to evaluate accurately its potential compared with PuO_2-UO_2.

The use of plutonium alloys in spike form for water-cooled reactors was also raised in U.S. and Canadian papers. The more important advantages of this fuel include low fabrication cost, good irradiation stability at temperatures up to 400°C, reasonable corrosion resistance in pressurized water and high thermal conductivity. The disadvantages include low melting point and the high thermal expansion which causes problems when the fuel is clad with Zircaloy. In addition to physical and mechanical property data, the U.S. paper detailed developments on a wide variety of fabrication techniques. The "large scale" cryolite process reduction of PuO_2 with aluminium was described and data also given on casting extrusion, co-extrusion cladding, injection casting, drawing, rolling, roll cladding, Zircaloy cladding and welding. The fabrication of charges for the MTR and the Plutonium Recycle Reactor (PRTR) was also summarized.

In the Canadian paper, the physical properties of cast and annealed aluminium alloys containing 5 to 20 w/o plutonium were given; in addition investigations had been carried out on the sheath and core thermal compatibility, between the alloy and Zircaloy-2, the corrosion resistance and the irradiation behaviour of the clad alloys at temperatures up to 400°C under power reactor conditions. There was an increase in hardness but the core alloys were relatively volume stable, the increase being about 2%.

Conclusions

The main conclusions that could be drawn from this Conference were:—

1. Research and development on plutonium, its alloys and compounds as reactor fuels, is well under way in the three countries and considerable effort will be paid to the irradiation behaviour of these materials in the near future.

2. The basic research carried out on plutonium and its alloys is now becoming fruitful in understanding and interpreting the complex phenomena involved.

Reactors at the German Industries Fair

Emphasis this year on Argonaut-type Research Reactors

SEVERAL German concerns included nuclear sections in their exhibits at the German Industries Fair, Hanover, this year. Their interest reflected the advanced stage of several projects in Western Germany and the emphasis on research reactors.

AEG showed sections of their Argonaut-type research reactor which has a versatile core design. The fuel elements (20% enrichment) have their own cooling channel and are designed so that the inner graphite core may be withdrawn leaving an experimental hole of 90 cm in diameter. Experimental possibilities are restricted, however, by the low thermal neutron flux of 10^9 n/cm² sec. This reactor is to be installed at Gros-Welzheim near Kahl on the site of the first nuclear power station in Germany, a 15 MW boiling water type.

BBC-KRUPP had on display a model of their high-temperature gas-cooled reactor with a diagram of the reactor operation and a simulator capable of solving five different equations. This company is building a 15 MW HTGC power station for AVR at Julich.

A model of an organic moderated ship reactor was shown by **INTERATOM** who are designing a propulsion unit of this type in conjunction with the Gesellschaft fur Kernenergie at Geesthacht.

SIEMENS displayed a model of their Argonaut-type research reactor at present under operation at Munich. They are building a second reactor of this type at Karlsruhe for the Kernreaktor Betriebsgesellschaft, and are planning to market low energy training reactors of 0.1 or 1 W thermal power. These reactors are expected to cost 250,000 to 300,000 DM, making them an attractive proposition as opposed to expensive reactor simulators. A 50 MW reactor for fuel element and material testings and the production of radioisotopes is at present under consideration by the Federal Government for construction for the Atomic Energy Commission.

B E T A

DANATOM'S 175 MW Design Study

DANATOM, the Danish Association for Industrial Development of Atomic Energy—a self-governing body associated with the Danish Academy of Technical Sciences—has recently published a design study of a 175 MW gas cooled nuclear power station which they have named BETA.

While there is not, as yet, any definite intention of proceeding with construction, the design study of BETA has been made as realistic as possible—even to the selection of a suitable site—with the threefold object of assessing the nuclear potentialities of Danish industry, assisting the utility companies in the evaluation of future tenders, and estimating the actual construction costs in Denmark, and more than 50 separate reports and studies have been carried out on various aspects of design, by members of DANATOM and by various industrial companies and groups. The English summary of the report runs to some 113 pages.

General Survey

BETA is a gas cooled natural uranium station with one reactor, six heat exchangers and two turbine sets. The output first selected for design purposes was 150 MW, this being considered the largest unit which the Danish grid system could use for some years to come. As design proceeded, however, it was found that estimates had been too much on the conservative side, and the final rating was optimized at 175 MW. The site selected is in North Zealand, on a comparatively tideless fjord, the area being part of the existing Kyndby station of the Isefjord Power Co.

As would naturally be expected, the station design is based on British second generation stations with the notable exception of the blowers, which are based on a boiler fan manufactured in Denmark. The cost has been estimated at £112 per kW installed capacity, and generation costs of 0.68d/kWh.

Core

The graphite moderator is a 24-sided prism, with a height of 8.8 m (28 ft 10½ in.) and a diameter of 14.7 m (48 ft 3 in.). There are 3,176 fuel channels, the lattice pitch being 203 mm.

The fuel elements are reminiscent of both Bradwell and Hunterston in that they have the helical fins and longitudinal splitters of the Bradwell element but are contained in separate graphite sleeves. These sleeves are slightly smaller than the fuel element channels—the respective diameters being 124 and 119 mm—to give a stagnant gas gap for additional insulation between the moderator and the coolant. The external diameter of the graphite sleeves is slightly coned to assist in this, as well as to guide the graphite sleeve during insertion. The fuel elements are supported in the sleeve from below by four graphite legs fitting into a groove in the sleeve. Magnox canning is used with 36 helical fins.

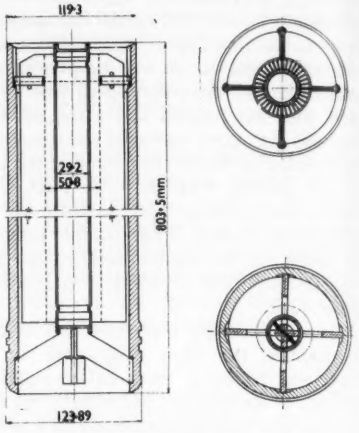


Fig. 1—Sections of fuel element and sleeve showing graphite legs.

An internal groove is provided at the top of each sleeve so that, if required, the elements may be removed from above by means of the servicing machine. Charging is normally from below.

The loading for a single channel consists of nine fuel elements supported by a non-fuelled bottom element, containing stop and trip gear and the gagging orifice for regulating the gas flow.

Control

Provision is made for a total of 150 cylindrical rods of stainless steel with 2% boron. From the figures given, the exact allocation of these rods is not obvious. To prevent instability, due to flux peaking with a large diameter core, the core is divided into nine zones, each zone being controlled by either one, two, or three rods, under independent automatic control to keep the outlet temperature constant in that particular zone. Nine rods will be reserved for compensation for xenon, and 10-20 will be used strictly as safety rods, the remainder being available as shim rods for trimming between the various zones.

All control rod mechanisms utilize permanent magnet synchronous motors operated from a variable frequency supply.

Pressure Vessel

The pressure vessel is a sphere of internal diameter of 21 m (68 ft 8½ in.) and plate thickness varying from 50-70 mm. The material is a normalized

TABLE 1 Main Parameters of BETA
(British dimensional equivalents are approximate only)

Net electrical output	175 MW
Thermal output	574 MW
Thermal efficiency	30.5%
Core	
Diameter (over reflector)	14.7 m (48 ft 3 in.)
Height (over reflector)	8.8 m (28 ft 10½ in.)
No. of fuel channels	3176
Lattice pitch	203 mm (8 in.)
Fuel elements per channel	9
Uranium rod diameter	29.2 mm (1.15 in.)
Uranium rod length	725 mm (28.8 in.)
Average conversion ratio	0.8
Excess reactivity available (cold, clean)	4.6%
Permissible burn-up	3000–4500 MWd/t
Expected average burn-up	2800–4200 MWd/t
Maximum thermal flux	3.26×10^{13} n/cm² sec
Average thermal flux	1.74×10^{13} n/cm² sec
Average thermal flux, fuel	1.12×10^{13} n/cm² sec
Temperature coefficient of reactivity, uranium	-1.9×10^{-5} per °C
Temperature coefficient of reactivity for graphite (unpoisoned, virgin charge)	-3×10^{-5} per °C
Average power density	2.1 MW/t
Central channel power	235 kW
Normal maximum temperatures	
Canning	425°C (797°F)
Uranium	550°C (1023°F)
Moderator	452°C (845°F)
Control	
No. of rods	
Auto. control zone	9, 18, or 27
Xenon	9
Safety	10–20
Shim	94–122
Total	150
Material	Steel, 2% boron
Length	7.5 m (24 ft 7½ in.)
Diameter	50 mm (1.97 in.)
Rod speed (auto.) max.	3 cm/sec (1.18 in./sec)
Total reactivity controlled	6.2%
Permissible change of load	
Step (max)	20%
Ramp (at least)	2%/min
Coolant Circuit	
Mass flow	2860 kg/sec (6306 lb/sec)
Inlet temp.	190°C (373°F)
Outlet temp.	380°C (716°F)
Pressure	11 ats (abs) (156.5 p.s.i.a.)
Pressure drop	0.4 at (5.7 p.s.i.)
No. of circuits	6
Power input to each blower	2.24 MW
Heat Exchangers	
Diameter	6 m (19 ft 8½ in.)
Height	25 m (82 ft)
Steam conditions	
H.P.	47 ats (abs) (668 p.s.i.a.) and 362°C (684°F) 274 t/h (604,200 lb/h)
L.P.	10.7 ats (abs) (150 p.s.i.a.) and 364°C (688°F) 137 t/h (302,100 lb/h)
Feed temperature	140°C (285°F)
Containment	
Pressure vessel I.D.	21 m (68 ft 8½ in.)
Plate thickness	50–70 mm (1.97–2.76 in.)
Design temperature	275°C (527°F)
No. of standpipes	
Top	216
Bottom	112

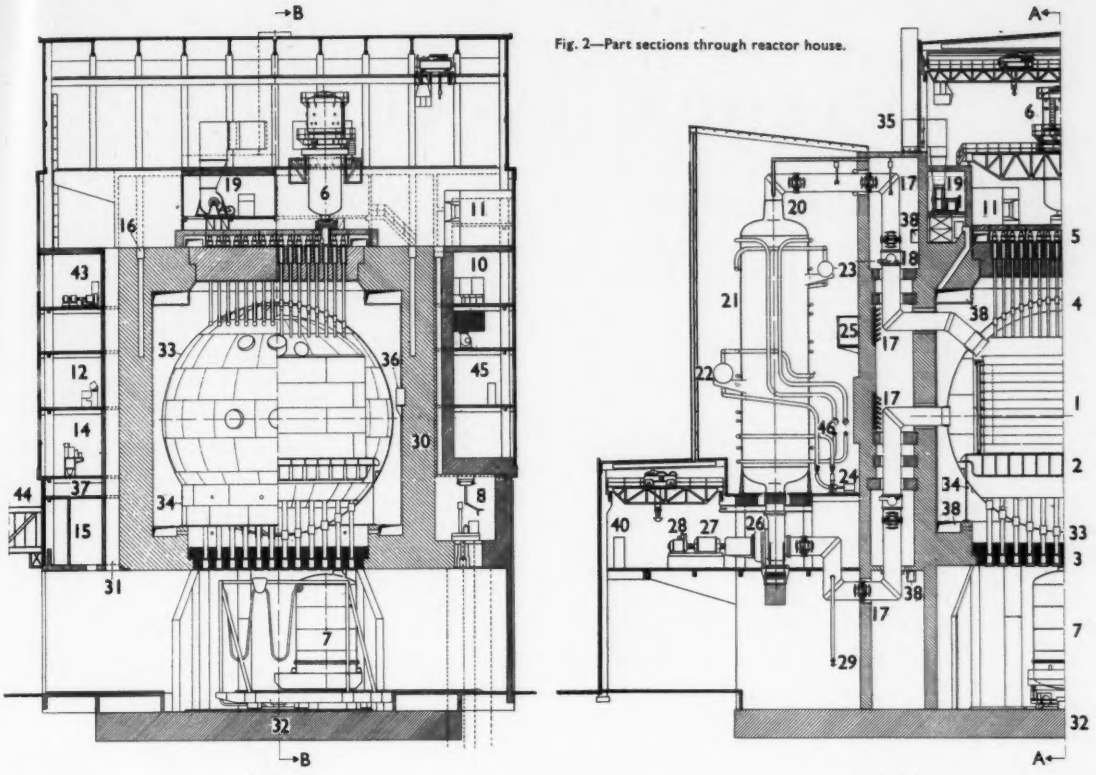


Fig. 2—Part sections through reactor house.

KEY

1. Reactor core.
2. Reactor diagrid.
3. Charge-discharge standpipes.
4. Control rod standpipes.
5. Control rod mechanisms.
6. Service machine.
7. Charge-discharge machine.
8. Fuel separation room.
9. Stairway and elevator.
10. Burst slug detection.
11. Service machine control room.
12. Charge-discharge control room.
13. Fuel separating control room.
14. 6 kV unit switch gear.
15. Fuel assembly room.
16. Mortuary holes.
17. Gas ducting.
18. Gas ducting main valve.
19. Concrete cooling equipment.
20. Gas ducting bellows.
21. Heat exchanger.
22. L.P. steam drum.
23. H.P. steam drum.
24. Boiler circulation pumps.
25. Walkway.
26. Gas circulator.
27. Main drive motor.
28. Auxiliary drive motor.
29. Piping to gas cleaning plant.
30. Biological shield.
31. Charge-discharge machine testing channel.
32. Reactor building slab.
33. Reactor pressure vessel.
34. Supporting skirt.
35. Cooling air funnel.
36. Thermal column.
37. Cable and piping duct.
38. Concrete cooling air ducting.
39. Boiler instrument panel.
40. Gas circulator instrument panel
41. Hoist well.
42. Equipment and fuel transport elevator.
43. Control rod panels and supplies.
44. Pipe bridge to turbine house.
45. Detector room.
46. Steam and feed-water mains.

low carbon Al-killed steel known as BH 36 KA/KW, of German manufacture, stated to be slightly less weldable than the steels used for the British stations. There are 216 standpipes in the top of the vessel and 112 at the bottom. The vessel is supported on an external skirt, and an internal skirt transmits the weight of the core to the external skirt.

The core is completely contained by an internal bell-shaped dome supported on the diagrid to form a thermal barrier for the hot gas emerging from the core; the space between the bell and the top of the sphere is swept by cool inlet gas.

Blowers

The blowers, one of the most interesting features of the design, are the "Variax" type, single-stage axial flow, with variable pitch impellers. The volume of gas handled by each fan at operating temperatures and pressures is 39 m^3/sec (1,437 ft^3 sec). The advantages of this type of blower include an efficiency of up to 90% at full station load and higher than 80% from 60%-110% load; the ability to start up fans while unloaded; a normal constant-speed a.c. motor direct-coupled and completely stepless regulation from zero to maximum output.

Steam Plant

The heat exchangers are of familiar construction, designed for dual-pressure work at 668 p.s.i.a. and 150 p.s.i.a., each having a total capacity of 302,100 lb/h. Each of the H.P. sections contains two economizers, one evaporator and one superheater section, while on the L.P. side there are one economizer, one evaporator and two superheater sections.

The two turbines are of Brown Boveri design, of 96.4 MW output. The turbines are 3,000 rev/min units with six L.P. stages (two triple flow L.P. cylinders in parallel) each exhausting to a separate half condenser.

Four stage bled steam feed heating is provided.

Charge/Discharge Arrangements

As previously mentioned, the reactor is arranged for bottom charging. It was felt that the additional cost of the charge/discharge machine added to the additional height of the station, while heavy, was worth while, in view of the ability to recharge a complete channel in one operation instead of removing the elements one-by-one. In addition, the capacity of the charge/discharge machine will enable axial inversion of the fuel, i.e., assuming the elements in a channel are numbered 1 2 3 4 5 6 7 8 9 from bottom to top, they can be removed and replaced in the order 6 7 8 9 1 2 3 4 5 to secure even irradiation of all elements. Control rod mechanisms are dealt with by the service machine on top of the reactor.

It should be mentioned that the study of both the charge/discharge and the service machine have not been carried as far as detailed component design.

The charge/discharge machine delivers elements to a fuel separation plant where the fuel element proper is separated from the graphite sleeve, using a machine for crushing the four graphite ribs supporting the element. It is proposed to re-use the graphite sleeves after a period of approximately 12 months.

OUTLOOK IN THE U.S.

Analysis of the Future Civilian Reactor Programme

$200 million Annual Expenditure Foreseen

BRIEF reference has already been made (*Nuclear Engineering*, May, 1960, p.225) to T.I.D. 8516, in which it was stated that Part IV would detail the U.S. future programme. It is now possible to give fuller particulars of the specific plans for all types of reactors and for the general pattern of nuclear development in the U.S. While at present the main problem facing the AEC —and for that matter all the rest of the world responsible for nuclear development— is to attain economic parity with fossil fuels, there is a long-range problem to be faced in the development of the breeder concept.

Following is a brief summary of the overall U.S. programme, according to the various types of reactors.

I. LIGHT WATER REACTORS

There seems a reasonable probability that these may be competitive where large single units are practicable and conventional costs are high. A major effort will be made to develop plutonium fuel.

A. Pressurized water reactors

Specific plans for the use of existing or authorized facilities are as follows:—

a. **Shippingport** will be modified to 150 MW and new core with flat plate oxide seed and blanket elements fitted. Plutonium, U-233, and Th may be tried out.

b. The **Yankee** plant at Rowe, Mass., due to become critical in 1960, operating at 110 MWe will provide experience with SS-clad slightly enriched oxide fuel elements, and solution poison for shutdown control.

c. The **Indian Point** plant, 151 MWe (255 MWe with oil-fired superheat) critical 1961, will give information on Th-U-235 fuel mixtures. A 5 MWe experiment is to be added to the **Saxton Nuclear Experimental Corporation's** plant at Liberty, Penn., scheduled for 1962.

d. A **40 MWt** reactor is to be built in California, in co-operation with the Department of the Interior, scheduled for 1962, to study low pressure process steam production economics.

e. A **16 MWe** unit, with 6 MWe oil-fired superheat, will be built to study small power PWR economics, and demonstrate bulk boiling. Criticality is scheduled for 1962.

In addition, naval experience with the submarine programme, the Army reactor programme, the *Savannah*, **SELNI** in Italy, and the Belgian reactor at **Mol**, are all expected to contribute design, construction, and operating experience.

Future plans include consideration of one more prototype which, it is felt, will be justified by research and experience gained with the reactors listed, and on which it is proposed to commence design in 1962, with construction commencing in 1963/4.

If the development work on the spectral shift concept appears promising, a prototype (50-100 MWe) will be commenced.

NOTE.—The spectral-shift reactor uses a mixture of heavy water and light water as a moderator. The initial proportion of heavy water is 75%-80%, gradually reduced to about 25% as the fuel burns, to decrease the neutron diffusion rate, thus increasing reactivity, and extending the fuel life.

It may also be desirable to initiate (1962) a 20-30 MWe prototype in a remote location to test reliability in these conditions.

B. Boiling Water Reactors

The **BORAX** series at NRTS, the **EBWR** at Argonne, the **Vallecitos** BWR, have all paved the way for the BWR. Plans for existing and authorized facilities include the following:—

a. Modifications now under way on **EBWR** will raise its output to 100 MWt, enabling studies of stability at higher power densities. Plutonium fuel and water chemistry will be two main lines of study.

b. The 16 MWe (with 6 MWe oil superheat) **Elk River** plant, scheduled for criticality in 1960, will assist larger plants by enabling testing of mixed thorium oxide and uranium oxide fuels, and the study of an intermediate heat exchanger in a boiling system.

c. Three privately built BWRs from which much valuable information is expected are the 5 MWe **Vallecitos** reactor, now being modified, the 180 MWe **Dresden** station, already on load, and the 48 MWe **Humboldt Bay** plant, scheduled for criticality in 1962.

d. A 50-75 MWe prototype is planned (criticality 1963) for the **Consumers Power Co.**, of Michigan, to demonstrate high power density (60 kW/litre).

e. A **50 MWe** prototype (commence 1960-1, critical 1964) is proposed to simplify and cheapen construction; reducing size, simplifying containment, eliminating high risers, and increasing power output per unit of water flow.

Overseas experience will be obtained from the 150 MWe **SENN** project, through an exchange agreement between the Commission and the Italian authorities. Until operating experience of the present reactors is available, no further large power reactors are contemplated by the Commission, although in the small reactor field, results from **Elk River, Humboldt Bay**, and the simplified project may indicate the need for a small prototype (20-30 MWe) in 1963/4. It has already been stated by a manufacturer that a 300 MWe station could be built on a fixed-price basis to produce competitive power in high-cost fuel areas.

C. Nuclear Superheat

Design studies have been under way for some time on superheaters integral with the reactor, and are being initiated on separate superheaters, i.e., separate steam-cooled reactors. Following are the plans for existing and authorized plants:—

a. **BORAX 5**, under construction at NRTS, scheduled for criticality in 1961, will commence with a limited number of channels producing superheated steam, and be gradually converted to an integral superheater reactor, permitting investigations of nuclear stability.

b. The **Pathfinder** (62 MWe) plant at Sioux Falls, is scheduled for criticality in 1962, and will provide operating data in a high density integral superheat core. Development work will continue on the use of lower enrichment in the superheater section.

c. The 16 MWe **BONUS** reactor for the Puerto Rico Water Resources Authority, scheduled for criticality 1963, will demonstrate the practicability of integral superheat for small plants.

If, from the results of these projects, it appears that substantially lower costs can be achieved, a 100 MWe prototype would probably be initiated in 1963, and, if successful, would probably encourage utilities to decide on a large (300 MWe) plant, say, by 1968/9.

II. ORGANIC-COOLED REACTORS

Organic-cooled reactors are expected to be competitive in high-cost areas by the middle 1960s. Research is primarily on claddings and alloys, lower cost organic make-up, and improved heat transfer characteristics. Long range work will be directed to plutonium recycling. The programme for existing and authorized facilities is as follows:—

a. The 5-15 MWt **OMRE** at NRTS is being modified and will be used as a fuel test facility, for determining decomposition rates and for heat transfer and surface fouling tests.

b. A new experimental reactor, the **EOCR** (40 MWt) is being constructed at NRTS (criticality 1963) and will have greater flexibility than OMRE, thus speeding up the rates at which alternative fuels, coolants, etc., can be investigated.

c. The 11 MWe unit for **Piqua,** Ohio, will go critical in 1961, and will enable a reasonable analysis of the organic concept, in this size, to be made.

d. Proposals have been invited for a **50-100 MWe** prototype (criticality 1964), the primary purpose being to provide data on improved fuels, such as Al cermet-clad uranium dioxide.

It is considered that by 1965/6, utilities may consider a 300 MWe unit for high-cost areas. Continuing research and development may also justify a 50-100 MWe prototype in the middle 1960s.

III. SODIUM-COOLED REACTORS

Although the practicability of sodium as a coolant has already been demonstrated, there are many problems with fuel elements and components which must be tackled. Since sodium is not a moderator, reactors may operate over a wide energy spectrum, and work is being done on both fast and thermal reactors.

A. Fast Reactors

The research and development programme for fast or epithermal reactors is long-range,

significant results being expected in the late 1960s, and will concentrate on long-life fuels, the utilization of plutonium and U-233 as fuels and U and Th as blanket materials, reliable (and less expensive) sodium components, and on fuel recycling. Plans for existing or authorized facilities are as follows:—

a. A plutonium cermet core will be installed in **EBR-I** when the current safety experiments are completed.

b. **EBR-II** is scheduled for criticality in late 1960 with a U-235 core. The second core will use plutonium, with on-site pyrometallurgical fuel processing.

c. The 94 MWe **Enrico Fermi** plant at Monroe, Mich., scheduled for criticality in 1960, will give information on U-10% Mo fuel, on fuel rotation and processing.

d. Military contributions will include the **SNAP** programme, which should yield much information on small high temperature reactors and materials operating in a fast neutron spectrum. An experimental intermediate reactor is included in the aircraft programme.

Valuable information should also be obtained from the British work at **Dounreay**, and from a prototype (800 MWt) under consideration, also from a 10 MWt plutonium-fueled unit being planned in France.

Future plans include a 100 MWe prototype which would not be started until two years' experience has been obtained from the present programme; say 1963/4.

B. Thermal Reactors

While it is thought that sodium-cooled thermal reactors could be developed to be economic in high-cost areas, great improvement is essential in the life of fuel elements. Work on the thermal reactor concept will not be expanded until operating results of the Hallam reactor can be obtained and research work will mostly concentrate on uranium carbide fuels and on major improvements in sodium components. Plans for existing facilities are as follows:—

a. The **SRE** will be operated for several years in support of the Hallam plant, on the testing of advanced fuels. Later, if the concept shows continued promise, it will be re-assessed as to its suitability for conversion to a high-temperature fuel test facility or to an advanced experimental reactor.

b. The 75 MWe **Hallam** (Nebraska) plant is scheduled for criticality in early 1962, and operating experience is expected to assist with the fast reactor programme, as well as thermal and intermediate.

No future commitments are envisaged, therefore, before about 1963/4.

IV. ENRICHED GAS-COOLED REACTORS

Plans for the use of existing and committed facilities are as follows:—

a. The 22.3 MWe **EGCR** at Oak Ridge is scheduled for criticality in 1962, and will be used as a flexible test facility. Work will be closely co-related to that carried out in Britain on AGR.

b. Philadelphia Electric's 28.5 MWe **HTGR** is scheduled for criticality in 1963, and is to be supported by a research programme which includes development of impervious graphite, uranium carbide-thorium carbide fuel dispersed in graphite, high-temperature components and fission product trap systems.

c. Military and maritime contributions include the aircraft nuclear propulsion direct cycle programme utilizing the **HTRE-3** at NRTS and expansion of the in-pile component test programme in **ETR**. The gas-cooled reactor experiment in progress for the Army will give important data on small water moderated SS-clad uranium oxide cermet cores, and uranium oxide-beryllium oxide pellet cores; on nitrogen as a coolant; on closed-cycle gas turbines.

In addition to alternative coolants, investigations include high burn-up fuels at surface temperatures of 1,700°F (927°C) or higher. Much valuable information will also be obtained from co-operation with the U.K. on **DRAGON**, the OEEC project. Future plans foresee a 100 MWe prototype initiated in the middle 1960s, the type depending on the results obtained from the EGCR and HTGR approaches; it is believed that a 300-500 MWe station could be competitive in high-cost areas by the early 1970s.

V. HEAVY WATER REACTORS

While attention will be devoted towards critical problems associated with fuel management techniques, extending reactivity lifetime, minimizing loss of heavy water and attempts to reconcile simultaneous needs for a cool moderator and a high coolant temperature, information obtained from other countries will be used to the fullest possible extent, and negotiations are under way for an expanded programme of co-operation with Canada, whose 20 MWe **NPD** and 200 MWe **CANDU** are scheduled for criticality in 1961 and 1965 respectively. Plans for existing and authorized facilities are as follows:—

a. The **HWCTR** at Savannah River (criticality 1961) will provide irradiation tests on fuel elements, and experience with pumps, valves and instrumentation.

b. Research and development is proceeding on a co-operative basis on the **50 MWe project** of the East Central and Florida West Groups. If built, the reactor is scheduled for criticality in 1963.

c. A 17 MWe **pressure-tube** reactor is being designed under a contract between the Commission and the Carolinas-Virginia Nuclear Power Associates, Inc., and is scheduled for criticality in 1962.

d. The **PRTR**, an experimental pressure-tube facility, to investigate plutonium recycling economics, is scheduled for criticality in 1960.

It is believed that from combined U.S. and Canadian experience it will be possible to decide by 1966/7 whether construction of a large reactor is justified.

VI. AQUEOUS HOMOGENEOUS REACTOR

Research on this concept will be continued on a long-range basis, on **HRE-2**, in an endeavour to solve some of the outstanding problems—core corrosion, remote maintenance, fuel stability, low steam conditions, which at present tend to outweigh the inherent simplicity of the fuel cycle, and the breeding potentialities. If successful, a third experiment might be built in 1962/3, and a prototype of about 50 MWe, in the late 1960s.

VII. NEW CONCEPTS

Many new reactor concepts are the subject of research in what may be termed "critical areas," i.e., key items of the scheme are being closely evaluated, with the prospect of a prototype or experimental reactor following, if the indications are favourable. Amongst such are the following:—

a. **Fused salt,** utilizing a mixed salt solution of fissile and fertile materials circulated through a heat exchanger, to obtain high temperatures at low pressures, and simple fuel processing.

b. **Fluidized Bed,** with a fissile/fertile mixture maintained in a fluidized state, under turbulent conditions, with water or an organic, the advantages being high power density and ease of charge/discharge.

c. **Paste or Suspended Fuel,** a similar concept to the fluidized bed, except that the bed is kept in a laminar, non-turbulent condition, reducing particle attrition.

d. **Supercritical Water Cooled.** Refers to operation above the critical pressure of water (3207 p.s.i.) not to reactor criticality.

e. **Slurry,** a fluidized fuel system with small size of particles, so that the fuel stays in suspension under operating conditions.

f. **Advanced Epithermal,** a compromise design between slow and fast reactors, with some moderation by graphite or beryllium—optimized for U-233—and sodium cooling.

g. **Pebble Bed Gas Cooled.** Fissile, fertile and moderator material in the form of balls or pebbles. High thermal efficiency and low fuel cycle costs are the desirable features.

h. **Solid Moderated, Steam Cooled,** where heat from the fuel is radiated to the moderator (graphite, beryllium oxide, zirconium hydride) which is cooled by water or steam, with the object of attaining high thermal efficiency.

i. **Alternate Coolant Fast Reactor.** Mercury, lead, lithium, sulphur, as alternatives to sodium, to increase efficiency and reduce costs.

Experimental reactors which are under construction are:—

a. The Los Alamos Molten Plutonium Reactor Experiment **LAMPRE.**

b. **TURRET,** a high temperature gas cooled reactor, also at Los Alamos, is intended to establish the feasibility of gas coolant at, or above 2,000°F (1,093°C) as well as the problems of handling a highly active primary system.

VIII. NUCLEAR TECHNOLOGY

In addition to the specific projects already mentioned, there is, of course, a vast research effort on fuels and materials, fuel reprocessing, waste disposal, nuclear physics, reactor components, and reactor safety. In this last section may be mentioned the reactor kinetics programme with the **SPERT** (Special Power Excursion Reactor Test) series and the Kinetic Experiments on Water Boilers, or **KEWB.** The complete safety programme is as follows:—

a. The reactor kinetics programme will continue with the operation of the **SPERT** (Special Power Excursion Reactor Test) series of reactors and the **KEWB** (Kinetic Experiments on Water Boilers) reactor. The SPERT reactors are designed to obtain transient test data for the full range of heterogeneous water reactors including swimming pool, boiling water, heavy water and pressurized water reactors. An additional feature of the SPERT II reactor is the case with which it can be modified to conduct transient testing of organic systems. Major effort under the SPERT programme will be made to obtain data and mathematical models which will be useful not only in design and for hazards analysis of reactors, but also in establishing standard test procedures for providing the dynamic characteristics of new reactors before they are licensed for operation.

b. The KEWB programme should be completed in the calendar year 1961 with the test of a cylindrical core. KEWB data will have wide application not only to an understanding of homogeneous reactor kinetics, but also to safety analysis of chemical processing plants.

c. Additional support work will be provided to the reactor transient testing programme in the field of kinetics analysis, transient heat transfer, and bubble dynamics.

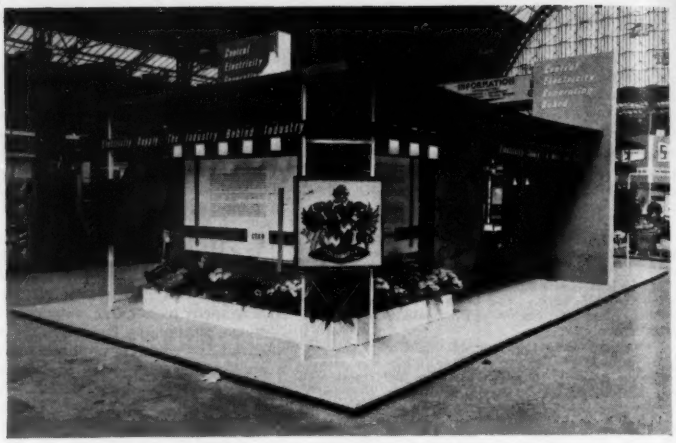
d. The effort to determine the true hazard of metal-water reactions will try to correlate laboratory tests and theory with capsule type in-pile experiments and finally, full-scale core melt-down measurements. Fission product release studies will be made in-pile for the first time and generalized theories developed to allow accurate prediction of both fission product release and metal-water reaction in any credible accident.

e. The high cost of containment design will be attacked by investigations of alternate methods of protection such as confinement in ordinary buildings, and the use of energy sinks and vapour suppression schemes. In addition, data and theories of the response of containment structures to dynamic loading will continue to be investigated in order to eliminate any excessively conservative design criteria and their concomitant excessive costs.

The report concludes with an attempt to estimate the costs, not only for research and development, construction of prototypes, etc., but in such matters as waiving fuel charges, operation costs, and general engineering charges. The gross total, including prototypes, but not commercial-size plants, is expected to be $180-200 million a year, the bulk of which will be obtained from the government, although substantial contributions are expected from industry.

Fuel Efficiency And Power For Industry Exhibition

OLYMPIA, APRIL 27—MAY 6



The CEGB stand with an illuminated map of nuclear power stations.

In an attractive display, the **Atomic Energy Authority** illustrated the production of fuel for reactors, including cut-away exhibits of fuel elements. The progress of the current nuclear programme was portrayed showing how new types of reactors, on which research work is now proceeding, could cut the cost of nuclear power in the future. Marine nuclear propulsion methods were also displayed.

British Boiler Accessories showed heat exchangers with special reference to heat recovery, and three basic types of steam accumulators adapted to fluctuating steam loads.

Thermal insulation materials, Caposite amosite asbestos and Rocksil rock wool were displayed by **Cape Asbestos** who have supplied insulation material for Berkeley.

The **CEGB** displayed a map which, by means of electrical animation of coloured lamps, described the functions of the Board with details of the current programme of construction of nuclear power stations. An illustration showed the importance of the grid and super-grid high-voltage transmission systems.

Chemical and Insulating had on display a wide range of heat insulating materials based on light magnesium carbonate. These include materials of 85% magnesia, metadextramite and dextramite suitable for temperature applications of up to 2,000°F.

Darlington Insulation, who are currently engaged on work at Bradwell, had on display models, photographs and samples of their insulation work.

Electrical precipitators were the subject of the **Holmes** stand together with other types of filters, blowers, dryers and dust collectors.

Honeywell Controls displayed automatic controls for heating, ventilating and air-conditioning together with automatic controls and safeguards for boilers, burners and furnaces. Temperature and humidity control systems were also displayed.

The steam generation and combustion activities of **International Combustion** were well displayed on their stand. These included a Lopulco three-roller mill recently developed for the CEGB's 1,000MW High Marnham Power Station and a scale model of a tilting corner oil burner.

Keith Blackman exhibited a range of Aristocrat centrifugal fan impellers and a Cyclogal high efficiency dust and grit collector. Their stand also included a working model of the Keith Blackman-Broman Ekstrom shot cleaning system which demonstrates the method of cleaning heat convection surfaces in boilers, superheaters, economizers, etc.

The main feature of the **Kelvin and Hughes** exhibit was a system of automatic boiler control for shell boilers demonstrated by means of a simulator unit into which varying combustion conditions can be channelled.

Midland Industries showed steam traps of both bimetallic thermostatic and ball floats, with thermostatic air release as well as pressure reducing valves, stop valves, high pressure hot water valves and other accessories. A new range of diaphragm valves, one with full-way characteristics, was also displayed.

Morgan Crucible showed their ranges of jointing compounds, high temperature grease, carbon brushes, brush holders and contacts and **Morgan Refractories** displayed high grade bricks, insulating and low heat storage refractories, and mouldable and castable refractories, etc.

Another insulation exhibitor was **Newalls Insulation** who had examples of their new Newtherm, calcium silicate insulation among their exhibits. A service on their stand included information regarding insulation for nuclear power stations.

Permutit had on display samples of their complete range of water treatment plant and equipment and a range of chemical pumps made for chemical dosing and high pressure boiler feed conditioning. Their latest techniques on ion exchange and precipitation processes were also illustrated.

Rheostatic were prominent among the control exhibitors with a range of Satchwell automatic temperature controls.

Rubery Owen (Heating), large manufacturers of oil-firing equipment, had a comprehensive exhibit.

An interesting feature of the **Ruston and Hornsby** stand was a Ruston 6YE generator set with a 50 cycle operation and a rating of 48/75 kW at 1,000-1,500 r.p.m.

A cut-away model of **Simon-Carves** latest electro-precipitator developed for collection of fume and dust particles was displayed and an animated panel showing the basic principle of electro-precipitation. The stand also included a working demonstration of electro-precipitation taking place.

Equipment concerned with fuel efficiency in steam raising by the application of mechanical draught techniques with fans, was shown on the **Sturtevant Engineering** stand. Other exhibits included electrostatic precipitators for the cleaning of boiler flue gases, washers and scrubbers, mechanical collectors, bag filters and unit dust collectors.

John Thompson's stand included heat exchangers and nuclear developments, including nuclear fuel handling in the general display of steam-raising equipment and ancillary equipment for industrial steam users.

Versil had a comprehensive display of thermal insulation for pipes and boilers, glass fibre air filters and sound insulation.

Electrostatic precipitators by Sturtevant Engineering.

1960 Nuclear Congress

Future Instrumentation Requirements Discussed at Recent Conference in New York

NUCLEAR instrumentation was one of the seven major subjects discussed at the 1960 Nuclear Congress held in New York during April. The Congress was sponsored by the Engineers Joint Council, an association of some 28 American engineering and scientific organizations. About 10% of the 60 papers were concerned with instruments.

Possibly the most interesting instrument paper was "Present Needs in Instrumentation and Control Technology for Nuclear Power Reactors" by F. C. Legler of the U.S.AEC. As a prelude to the initiation of a long term instrumentation programme, the Commission invited instrument contractors to submit their comments on research and development requirements. Mr. Legler summarized these opinions.

In the field of neutron flux instrumentation, ionization chambers and counters without special cooling arrangements are needed for neutron flux level measurement in temperature environments above 570°F. Neutron sensors for use in fast reactors should be smaller than those presently available and they should also resist corrosion by sodium at 1,200°F. Other essential items for a sodium-cooled reactor are an ionization chamber with improved gamma compensation at intermediate power levels and a start-up counter capable of yielding improved flux level information in 10^6 r/h gamma fields.

There is need too for an ionization chamber or counter system capable of operating over 10 decades of reactor power. The photomultiplier tube and scintillation counter combination with its wide dynamic range should find application in this area if problems of gamma discrimination, radiation damage, and temperature sensitivity can be solved. For operation in the core of a high temperature reactor miniature sensors with long life and reliability are required. Already one manufacturer has produced an ion chamber of ¼ in. o.d. designed to operate in 650°F water. Apart from low susceptibility to radiation damage, these units must have an operating life of 10^{21} n/cm².

Signal cables for use with in-core neutron sensors must have low noise characteristics, high resistance insulation and low susceptibility to damage by high temperatures, neutrons and gamma radiation. At present co-axial cable with specially treated silica base insulation shows promise of satisfactory service at 1,000°F and above.

To reduce cost and improve reliability there is a call for neutron sensors with output currents high enough to operate relays directly in protective channels. In positions where thermal neutron flux is depressed by control rods, coolant loops and so on, there is a need for fast neutron flux measurement. In neutron sensors generally, chamber voltage supplies, amplifiers and high impedance circuits should be eliminated; the Savannah River neutron thermometer was quoted as an example. New methods must also be developed for calibrating and checking the operation of sensors located in inaccessible places.

Turning now to reactivity control, in order to enhance neutron economy the amount of mechanical equipment in a core must be reduced. Methods that show promise include moderator level control, control by poisoned coolant, spectral shift control, leakage flux control and reflector control. Improvements could also be made in control rod drives to reduce complexity and also to present a clear area on the reactor loading face.

There is a lack of experience with burnable poison distribution in fuel matrices and in coolants. The relative advantage of lumped and homogeneous poisons and the problem of helium gas release from boron poison must be investigated before any large-scale use of this method of coarse control can be used.

Techniques for automatically decreasing the effective neutron multiplication factor in a core at low temperature should be investigated in order to reduce cold-coolant accident hazards in multi-loop reactors. This calls for a mechanism which must be reversible and must be an inherent part of the fuel-moderator-absorber complex. Another important requirement is a highly reliable automatic start-up system for use by plant operators having a limited amount of training and experience in reactor physics. Automatic devices for controlling coolant flow in individual fuel channels would offer greater efficiency than present fixed-flow orifices. Electronic plant simulators are needed so that control systems can be checked for long-term drifts and sudden abnormal power changes.

Additional equipment is necessary for scanning in-core sensors and processing in-core measurement data for transmission via carrier systems to the outside of the pressure vessel. For temperature or neutron sensors located in removable fuel element assemblies methods of rapid disconnection must be devised. In-core transducers with output signals in digital form would eliminate zero drifts and facilitate data processing.

So far as non-nuclear instrumentation is concerned developments in sodium-cooled reactor technology should include methods of calibrating electromagnetic flowmeters in non-uniform magnetic fluxes and compensating for the effects of magnetic flux changes and temperature changes on the stability and reproducibility of flow measurements. There is also a requirement for continuously determining the impurity content of sodium; for locating and identifying objects and performing manipulations beneath the surface of sodium or organic liquids. Sonar techniques show promise in this respect.

For all types of reactors instruments are needed for locating interfaces in coolants. In water reactors it is necessary to know the location of water-steam interfaces in heat exchangers, in pressure vessels and in pressurizers. A high temperature ultrasonic liquid level sensor capable of operating at 1,000°F is being developed for the AEC.

For reactor core applications of non-nuclear instruments improved devices are required for measuring fuel element and coolant temperatures, coolant flow rates and levels, pressure drops, bulk steam-void fraction and local steam-void fraction. Sometimes such instruments have to respond in less than 0.5 sec; in all applications they must be resistant to high temperatures and to radiation. For operation at 1,500°F electrical resistance type temperature sensors are needed with the following characteristics: low calibration shift, 1 sec or less time response, low susceptibility to damage by radiation.

Instruments, Electronics and Automation

Exhibition at Olympia, London, Opens May 23

NUCLEAR equipment is again prominently featured at the Instruments, Electronics and Automation Exhibition which opens at Olympia, London, on May 23. This, the third of these biennial exhibitions, is said to be twice as large as its predecessors—a reflection, no doubt, of the rapid expansion of the instrument industry.

In spite of this expansion, however, the proportion of companies with exhibits of nuclear interest has not changed to any great degree. In many cases the smaller concerns manufacturing nuclear instruments have become absorbed into some of the larger groups. At a rough glance about 25% of the 500 or so exhibitors are making a specific contribution to nuclear engineering technology. Rather more than 5% of the total are actually concerned with the manufacture of nuclear instrumentation.

Our preview of the exhibition this year is designed to show at a glance the companies that are primarily concerned with the production of nuclear equipment. For this reason we have chosen to classify exhibits under five main headings: nuclear instruments, data handling, process control, test equipment, and materials. The floor plans on the facing page have been similarly coded.

Preview of Exhibits

A.E.I. (D 152)
TEST EQUIPMENT. Leak detector diode and control unit. Sensitivity of the order of 10^{-8} litre micron/sec.
PROCESS CONTROL. New D.C. potentiometric recorder with 4-in. chart and multi-colour printing. New flow recorder being demonstrated.
DATA HANDLING. BSD computer for Berkeley. Designed for analysing the output from scintillation counters in the precipitators. The equipment can memorize the previous 48 counts from each of 400-600 channel groups.

A.E.I. (E 213)
DATA HANDLING. 955 analogue computer solves linear and non-linear differential equations. Can be used for studying dynamic performance of physical systems.

A.O.I.P. (R 831)
NUCLEAR INSTRUMENTS. Equipment for determining the amount of radioactivity in air by means of electrostatic precipitation. Dosemeters.

A.P.T. Electronic Industries (P 650)
PROCESS CONTROL. Fully transistorized and hybrid circuits (transistors and valves) sub units. Valve test set.

Advance Components (C 107)
PROCESS CONTROL. Transistorized counter. Power packs.

Airflow Developments (B 66)
PROCESS CONTROL. Pilot tubes in S.S. Portable test equipment. Manometers. Miniature air blowers for cooling electronic equipment.

Alexander Controls (G 318)
PROCESS CONTROL. Alcon solenoid, air-operated and motorized valves.

Alto Instruments (R 816)
PROCESS CONTROL. Altoflux induction flowmeter; particularly suitable for metering slurries, aggressive chemicals and solids in suspension. Pipeline sizes from 1 mm dia. to 72 in. bore. Special models for high-pressure, high-temperature applications.

Ampex Electronics (S 863A)
DATA HANDLING. Magnetic tape, recording and reproducing equipment for storing nuclear data.

Ardente Acoustic Laboratories (S 865)
PROCESS CONTROL. Miniature electronic components—amplifiers, rotary multi-bank switches, transformers, potentiometers.

Audley Engineering (K 454)
PROCESS CONTROL. Audio Annin control valves for pressures of up to 6,000 p.s.i. Wee Willie valve for extremely small flows at pressures of up to 50,000 p.s.i.

Avo (D 156)
NUCLEAR INSTRUMENTS. Hot-spot monitor measures beta, gamma and X radiation from 0.05 to 100 r/h. Lightweight, portable; hand probe enables user to remain at a distance from source being measured.

B. and K. Laboratories (E 203)
DATA HANDLING. New 120-ft tape loop magazine.
NUCLEAR INSTRUMENTS. Vibrating reed electrometer for C^{14}, H^3, S^{35} determinations.

B.I.C.C. (R 813)
PROCESS CONTROL. Mineral insulated flexible thermocouple assemblies.

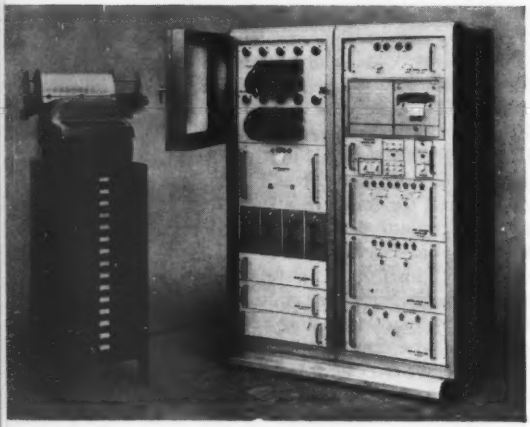
Bailey Meters and Controls (L 507)
DATA HANDLING. Data logger automatically prints out measured variables. Working simulation of a fully transistorized control system for process plant.
PROCESS CONTROL. Meters and recorders for flow measurement.

Baird and Tatlock (N 603)
TEST EQUIPMENT. Automatic titration equipment. Multiple geiger counter chromatogram scanner.

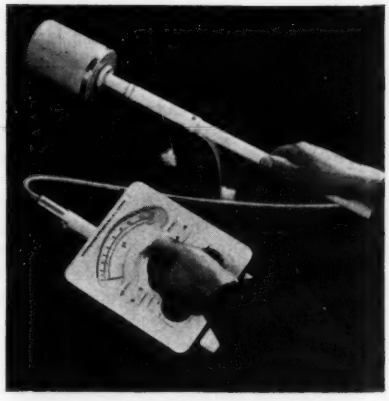
Beckman Instruments (R 805)
DATA HANDLING. Transistorized systems for handling physical valves. Beckman 123 data logger.
TEST EQUIPMENT. Gas analysers.
PROCESS CONTROL. Recorders.

Blackburn Electronics (Q 710)
DATA HANDLING. Blackburn data handling modules enable several parameters to be monitored continuously.

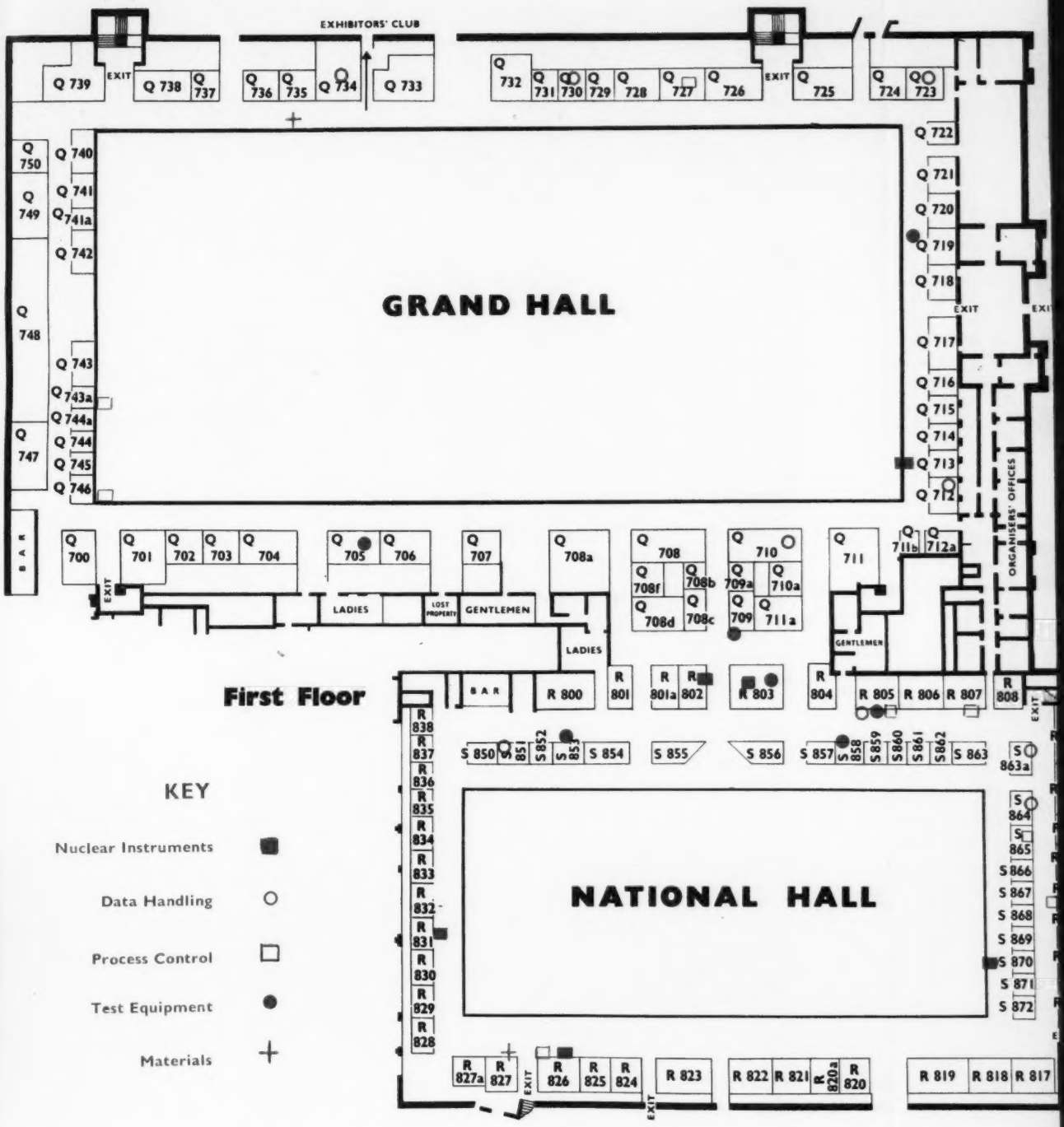
British Arca Regulators (R 807)
PROCESS CONTROL. Low-priced electronic strip chart recorder. Valves.

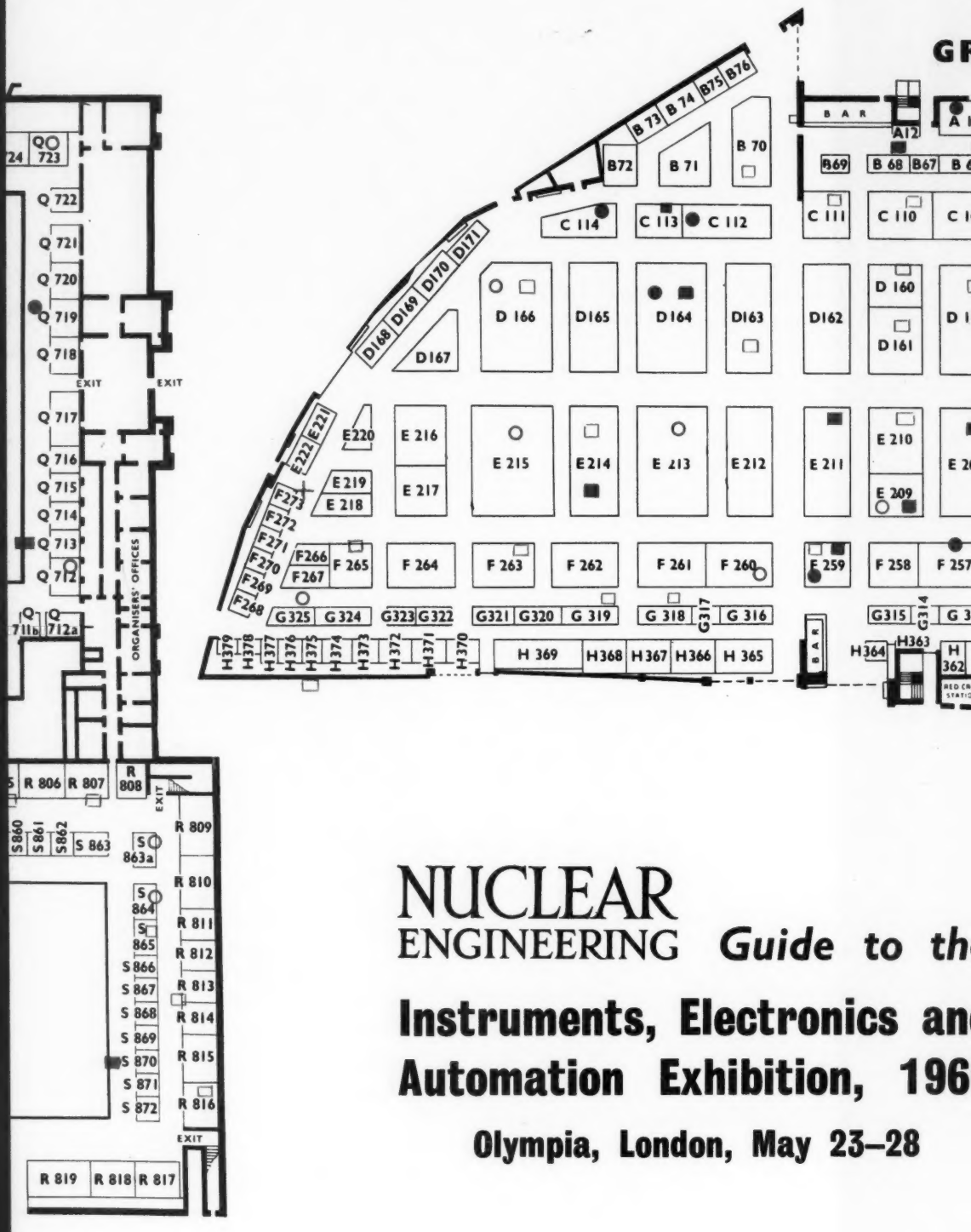


Blackburn data logger for monitoring strain gauge, thermocouple or other transducer outputs.



Avo hot-spot monitor: hand probe enables user to remain at distance from source being measured.


EXHIBITORS' CLUB
GRAND HALL
NATIONAL HALL
First Floor
KEY
Nuclear Instruments
Data Handling
Process Control
Test Equipment
Materials
EXIT
LADIES
GENTLEMEN
LOST PROPERTY
BAR
ORGANISERS' OFFICES

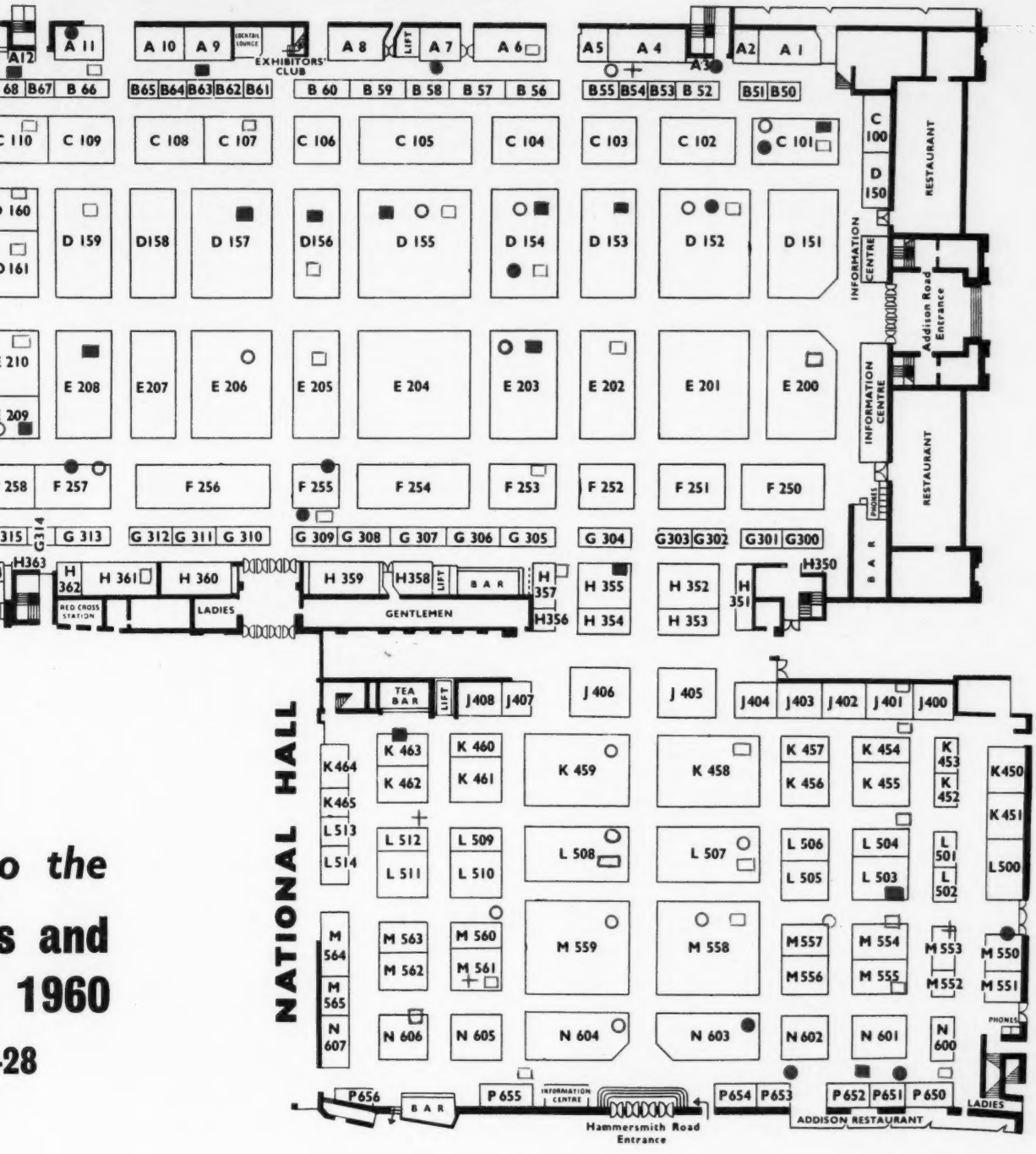


NUCLEAR ENGINEERING *Guide to th*

Instruments, Electronics an
Automation Exhibition, 196

Olympia, London, May 23–28

GRAND HALL (Ground Floor)



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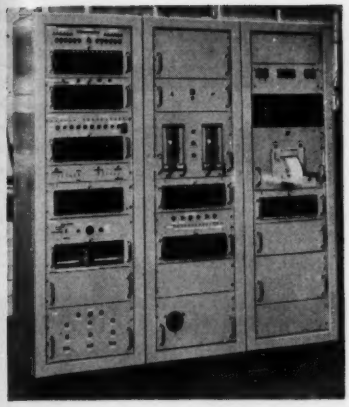


Three cubicle temperature scanning equipment showing logical element bins with standard Data-pac logical elements in position. (English Electric.)

Bulmers Business Machines (S 864)
DATA HANDLING. Addo-matic storage system, digital printers; punch card controller unit; tape readers.

Burndept (B 68)
NUCLEAR INSTRUMENTS. BN 110 ratemeter has two detectors—a geiger for beta/gamma and a scintillation counter for alpha. 140 7C fast neutron monitor. Universal scintillation counter. Portable, battery-operated, the BN 119 nucleonic thickness gauge can determine the thickness of zinc plating on a steel base. Radiation switch.

Cambridge Instrument (F 259)
NUCLEAR INSTRUMENTS. Control rod position indicator.
PROCESS CONTROL. In-line scanning recorder selects and scans from 20 up to 400 points.
TEST EQUIPMENT. Helium-in-air analysis outfit with electronic recorder/controller.

Carlo, Erba (Q 709)
TEST EQUIPMENT. Modular gas chromatograph, Fractovap Model C; automatic process chromatograph, model 110.

Colvern (Q 723)
DATA HANDLING. Shaft digitizers (encoders) for analogue to digital conversion from 7 digits to 10 digits.

Coulter Electronics (Q 743A)
PROCESS CONTROL. Particle counter in 0.7 to 200 micron range with 0.5% accuracy.

Crosby Valve (F 253)
PROCESS CONTROL. 16-in. Masoneilan double-seated control valve. Valves featuring wide ranges of different control arrangements.

D.S.I.R. (E 214)
PROCESS CONTROL. Thermocouple output simulator for calibration within the range 0 to 1,100°C.
NUCLEAR INSTRUMENTS. Position of a rotameter float measuring low flow rates at high pressure can be detected by using a radioactive float and geiger counter.

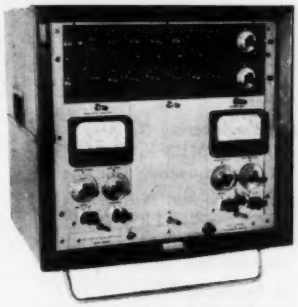
Dawe Instruments (Q 727)
PROCESS CONTROL. 250 W Soniclean generator for cleaning small components.

Data Recording Instrument (G 325)
DATA HANDLING. Tape handling machine with start/stop time better than 4 millisec at 150 in./sec.

de Havilland Propellers (Q 730)
DATA HANDLING. Anatrol equipment for on-line process control. Data acquisition and monitoring equipment.

Degussa (M 561)
PROCESS CONTROL. Thermocouples. Wire and assemblies for temperatures of up to 1,800°C.
MATERIALS. Sintered oxide ceramics.

Doran Instrument (S 858)
TEST EQUIPMENT. Automatic titrimeter.



New Ekco N160 automatic scaler.

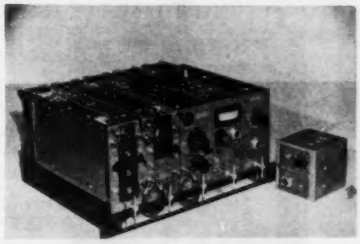
Dynatron Radio (E 208)
NUCLEAR INSTRUMENTS. N 107 test set; N 108 timing unit; stabilized power units for geiger tubes, ionization chambers and counters; coincidence unit; single channel pulse analyser. Soil density and moisture measuring equipment, portable, battery operated, using a sealed 10 mc radium/beryllium source.

E.A.L. (S 851)
DATA HANDLING. 231 R Pace analogue computer. TR-10 analogue computer. X-Y recorder. 8-channel recorder.

E.M.I. Electronics (D 166)
PROCESS CONTROL. 3-D TV system designed to facilitate handling of radioactive materials.
DATA HANDLING. Analogue (EMIAC II) and digital computers (EMIDEC 1100 and 2400). Figure reading electronic device.
NUCLEAR INSTRUMENTS. Health monitors.

Ericsson batch counter, type 188A.

Ekco Electronics (E 208)
NUCLEAR INSTRUMENTS. Reactor instrumentation. Combined automatic scaler and timer with overall resolution of 1 microsec. Universal scintillation counter for gamma counts. Moisture gauge for wet-end working in the paper industry. Level gauge. Chronomatic paper scanner for identifying different radioisotopes.



Ericsson 200A units mounted on shelf unit.

Electrothermal Engineering (G 319)
PROCESS CONTROL. Surface heaters including armoured pipe, heating tapes, thermocord, and flexible furnace. Electronic thermometer.

Elliott Automation (D 155)
DATA HANDLING. Complete Panellit 609 industrial information system incorporating an 803 digital computer.
PROCESS CONTROL. Wide range of valves made by subsidiary companies.

Elliott Nucleonics (D 155)
NUCLEAR INSTRUMENTS. Control rod mechanism for a nuclear power station.

English Electric (E 215)
DATA HANDLING. Multi-point scanning equipment incorporating data-pacs (building blocks) for processing systems. (Risley will use the first model.) LACE Mk. T analogue computer for training reactor operators.

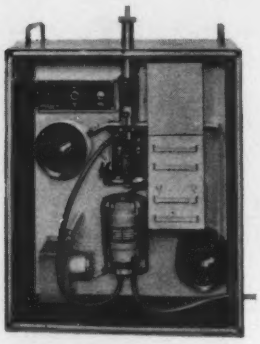
Ericsson Telephones (D 153)
NUCLEAR INSTRUMENTS. Unitized equipment comprising 24 sections each designed to perform a specific function. Portable health monitoring; Alpha/beta/gamma monitor; survey meter; field ratemeter.
DATA HANDLING. Logging systems for monitoring plant operations. Analogue/digital converter.

Ether and Electro Methods (E 205)
PROCESS CONTROL. Xactrol potentiometer recording controllers.

Evans Electroselenium (A 11)
TEST EQUIPMENT. EEL Mosaten densitometer for measuring film badge negatives.

Eversheds and Vignoles (K 458)
PROCESS CONTROL. 3-Term recorder/controller; supervisory control system; analogue/digital converter; servo motors; positioners.

Fairey Engineering (L 503)
NUCLEAR INSTRUMENTS. Nuclear magnetic resonance spectrometer.
PROCESS CONTROL. Electro-hydraulic servo valves. Chromized iron gas filter.



Automatic air pollution recorder (Fleming Radio).

Ferranti (N 604)
DATA HANDLING. Sirius and Argus computers.

Fielden Electronics (C 110)
PROCESS CONTROL. Thermocouple instruments and temperature recorder/controller; electronic control systems.

Fleming Radio (P 652)
NUCLEAR INSTRUMENTS. Radioactive dust sampling equipment; automatic air pollution recorder.

Foster Instrument (C 111)
PROCESS CONTROL. Temperature measurement.

Foxboro-Yoxall (E 202)
PROCESS CONTROL. Electronic controller/recorders.

General Controls (H 375)
PROCESS CONTROL. Precision potentiometers for position indication.

General Precision Systems (M 560)
DATA HANDLING. Simulator with power range from 1/10 W to 1,000 MW. D.C. analogue computer components.
TEST EQUIPMENT. Mercury vapour detector.

Griffin and George (R 803)
TEST EQUIPMENT.
NUCLEAR INSTRUMENTS. Marketed under licence from DIA Electrotechnick.

Cleaning small components with the Guyrota by Guyson Equipment.

Grubb Parsons (P 651)
TEST EQUIPMENT. Infra-red gas analysers for monitoring CO_2 circuits or for leak testing.

Guyson Industrial Equipment (Q 742)
PROCESS CONTROL. Semi-automatic equipment for handling small metal components or plastics.

Hendrey Relays (C 113)
NUCLEAR INSTRUMENTS. Gamma survey equipment for use in locating, estimating size and control of mining minerals or for stratigraphic measurements to a depth of 1,100 ft.

Honeywell Controls (E 200)
PROCESS CONTROL. New modular Electronik design embodies four self-contained and replaceable sub assemblies. Electrik Tel-O-Set miniature instrumentation.

Hunt and Mitton (H 357)
PROCESS CONTROL. Diaphragm-operated valves from $\frac{1}{16}$ in. to 14 in. bore; air actuators. Pneumatic recording controller.

Instron Engineering (Q 705)
TEST EQUIPMENT. Device for testing tension of radioactive specimens.

Integra, Leeds and Northrup (D 163)
PROCESS CONTROL. Multi-point recorders for up to 192 channels. Control rod position indicator.

K.L.G. Sparking Plugs (Q 735)
MATERIALS. Sealed terminals. Capable of withstanding exceptionally high temperatures and vacuum conditions.

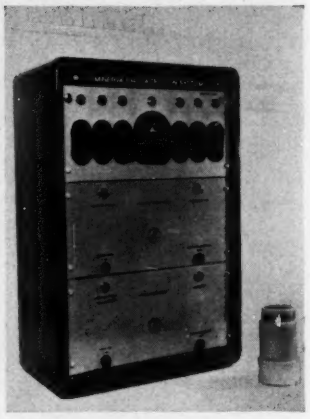
Temperature scanning equipment for Hinkley Point nuclear power station (Marconi Instruments).

Kelvin Hughes (F 257)
DATA HANDLING. Scanning and logging an unlimited number of process variables at high speed; re-presentation in digital form.
TEST EQUIPMENT. Ultrasonic flow detector.

George Kent (D 159)
PROCESS CONTROL. Mk. 3 Multelec strip-chart recorder and associated equipment.

Leeds Meter (J 401)
PROCESS CONTROL. Integrating and recording instruments. Turbine flow meter.

Lintronic (B 55)
DATA HANDLING. Conversion of signal output from an analogue simulator to digital form



Minerva control unit and signal panel for fire detection systems.

Lodge Plugs (M 553)
MATERIALS. Sintox impervious alumina ware for high temperature applications.

M.S.S. Recording (Q 712)
DATA HANDLING. System of outlining tape performance characteristics.

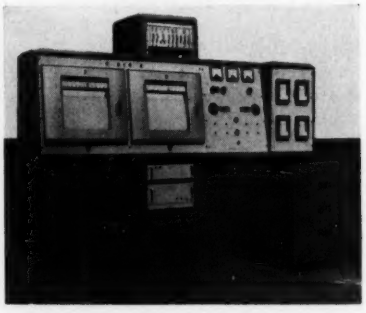
Marconi Instruments (D 157)
NUCLEAR INSTRUMENTS. Demonstrations of (a) Scintillation counter feeding a ratemeter governed by a BSD controller; (b) Development model of a temperature scanning system continuously monitoring a large number of thermocouples.

Marshall of Cambridge (B 63)
NUCLEAR INSTRUMENTS. Pulse height analyser, type HS 100. Magnetic pulse recorder, type MPR 103. Transistorized ring scaler. Automatic uranium assay equipment.

Minerva Detector (G 309)
PROCESS CONTROL. Fire detector unit based on a source and an open ionization chamber.
TEST EQUIPMENT. Gas detector.

Mullard (M 559)
DATA HANDLING. Number indicator tube for use in electronic counting circuits.

New Western (Engineering) (A 6)
PROCESS CONTROL. Instrument panels for nuclear power stations.

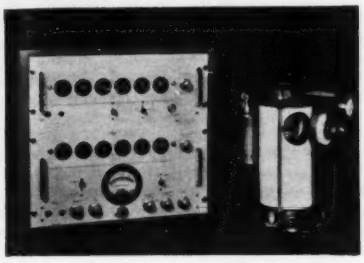


General Precision Systems' nuclear reactor simulator.

Normalair (R 826)
PROCESS CONTROL. Electro-hydraulic servo valves. Liquid helium transfer tubes.

Nuclear Enterprises (G.B.) (R 826)
NUCLEAR INSTRUMENTS. Scintillation phosphors; counters.

Panax Equipment (S 870)
NUCLEAR INSTRUMENTS. Scintillation counters. Scintillation castle. Pulse amplifier. High sensitivity gamma probe. Counting equipment. Ratemeter.



Low energy beta counting equipment including auto-scaler and scintillation counter (Panax Equipment).

Bruce Peebles (R 802)
NUCLEAR INSTRUMENTS. Range of Tracerlab units for which the company is the exclusive agent in the U.K.

The Plessey Group (M 558)
PROCESS CONTROL. Synchros, resolvers made by a Plessey subsidiary, Ketay which also specializes in remote indication.
DATA HANDLING. Hagan Kybernetes automatic data scanning and computing system.

Pye (D 154)
PROCESS CONTROL. 3-D TV equipment for handling radioactive materials.
TEST EQUIPMENT. Argon chromatograph.

Quickfit and Quartz (C 112)
TEST EQUIPMENT. Glassware ranging from laboratory to small production sizes Kjeldohl apparatus for nitrogen determination.

Racal Instruments (F 260)
DATA HANDLING. Voltage to frequency converter, fully transistorized.

Radiochemical Centre (H 355)
NUCLEAR INSTRUMENTS. Exhibit shows current uses of radioisotopes in industry—thickness gauging, static elimination, radiography, sterilization, well logging and so on.

Research and Control Instruments (D 164)
NUCLEAR INSTRUMENTS. Low background beta counter.
TEST EQUIPMENT. Automatic X-ray analysis.

Rotameter (E 210)
PROCESS CONTROL. Fluid measurement and control apparatus including units for determining density and level.

Royal Worcester Industrial Ceramics (B 54)
MATERIALS. Regalox high alumina ceramic components.

Saunders-Roe (R 826)
TEST EQUIPMENT. Strain gauges, pressure and load cells, torque meters.

Servomex Controls (E 255)
TEST EQUIPMENT. Transfer function analyser for determining frequency response of servomechanism and automatic control systems. Portable oxygen analyser.

Short Bros. and Harland (M 557)
DATA HANDLING. Small capacity general-purpose analogue computer, Simlac Minor.

Solartron Electronic Group (E 206)
DATA HANDLING. High-speed digital data conversion and printing. ERA—direct high-speed optical character reading device. Nuclear reactor control simulation.

Sperry Gyroscope (C 101)
NUCLEAR INSTRUMENTS. Reactor control equipment.
PROCESS CONTROL. Synchros and servo loops.
DATA HANDLING. Magnetic storage drums.
TEST EQUIPMENT. Introview flaw and corrosion detector.

Standard Telephones and Cables (K 459)
DATA HANDLING. New transistorized digital computer with magnetic tape or punch card input/output.

Swift, Levick and Sons (F 273)
MATERIALS. Columax permanent magnet material for nuclear magnetic resonance work, and for control purposes.

Taylor Controls (D 161)
PROCESS CONTROL. Transcope miniature series of control equipment. Sensaire Temperature transmitter.

Taylor Electrical Instruments (P 655)
PROCESS CONTROL. Panel meters with scale lengths of 2 in. to 5 in.

Techna (Sales) (Q 746)
PROCESS CONTROL. Miniature circuit reactors for protecting control equipment.

Technicon Instruments (P 653)
TEST EQUIPMENT. Continuous automatic wet chemical analyser.

Servomex transfer function analyser.

Teledictor (C 114)
TEST EQUIPMENT. Electro-magnetic eddy current unit for non-destructive examination of non-ferrous sections.

Telequipment (S 853)
TEST EQUIPMENT. Serviscope. Single and double Oscilloscopes.

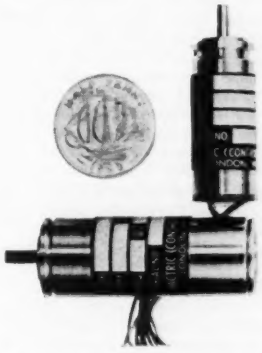
Torsion Balance (Q 719)
TEST EQUIPMENT. Kenton microhardness tester. Dial-type balance.

20th Century Electronics (Q 713)
NUCLEAR INSTRUMENTS. Photomultipliers; neutron counters.
TEST EQUIPMENT. Mass spectrometer leak detector; c.r. tubes.

Ultrasonoscope (A 3)
TEST EQUIPMENT. New miniature ultrasonic flaw detector Mk. 3 for on-site inspection. New range of search probes.

Vactric (Control Equipment) (M 555)
PROCESS CONTROL. Precision servo components.

Venner Electronics (Q 734)
DATA HANDLING. Punched tape readout; all electronic, transistorized digital clock. Transistorized analogue frequency meter.

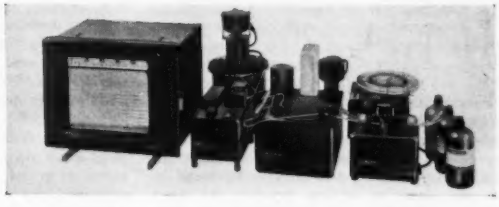


Vactric size 07 D.C. servo motor and 08 A.C. motor tachogenerator.

Waveforms (M 550)
TEST EQUIPMENT. Oscillosopes.

Williams and James (D 160)
PROCESS CONTROL. Wilmot Breeden electro hydraulic actuator system. Telesig positive displacement pumps.

G. H. Zeal (L 504)
PROCESS CONTROL. Electric contact thermometer; mechanical dial indicating and recording thermometer and manometers.



Autoanalyser for continuous automatic analysis of chromatographic fractions. (Technicon Instruments).

TRANSLATIONS

Résumés of Principal Articles

Dérèglement des Instruments (page 241)

En raison des conditions de sécurité absolue, à n'importe quel prix, les arrêts de réacteurs résultant de renseignements erronés ont tendance à augmenter. Tandis que ceci n'est pas très important pour les réacteurs de recherche, l'arrêt fortuit de réacteurs de puissance sans raison valable peut être coûteux.

Afin de mieux connaître les causes des arrêts intempestifs, Nuclear Engineering a fait une enquête se rapportant aux réacteurs qui ont fonctionné pendant une année au moins sans subi d'arrêts dûs au dérèglement des instruments.

Il en résulte que le coefficient de sécurité des installations électroniques et électriques devrait être augmenté, en particulier celui des amplificateurs à courant continu, des réseaux de courant de secours, du câblage. En outre des progrés sont possibles pour la conception et l'entretien des circuits comportant des relais. Les conséquences des résultats obtenus sont également discutées.

Un Dispositif de Protection Automatique pour un Réacteur Réfrigéré au Gaz (page 243)

La température atteinte par les éléments de combustible d'un réacteur réfrigéré par un gaz dépend de l'équilibre entre la chaleur produite et la chaleur évacuée. Le principal critère qui doit être satisfait par le dispositif de contrôle est l'exclusion de tout déséquilibre des conditions thermiques de sorte qu'un accroissement de température du combustible pouvant provoquer un dégagement de produits de fission dans le réfrigérant soit impossible. Un dispositif de protection automatique efficace doit tenir compte de plusieurs variables dont le flux, la période du réacteur, le débit, la pression et la température du réfrigérant gazeux.

La Mesure des Flux de Neutrons aux Températures élevées (page 245)

Les générations de réacteurs qui prendront la relève des réacteurs du type Calder Hall devront être equipées de détecteurs pouvant être utilisés à des températures élevées. Des chambres d'ionisation fonctionnant à 400°C ainsi que des compteurs de fission pouvant être employés jusqu'à des températures de 900°C sont actuellement en cours de fabrication. Une élévation future des ces limites d'emploi semble possible.

Le Domaine d'Utilisation des Calculatrices électroniques (page 248)

Un organisme envisageant l'achat d'une calculatrice électronique pour son département de recherche peut être tenté de considérer simultanément plusieurs éléments disparates de façon à réaliser quelques économies. L'article analyse quelques uns des caractéristiques essentielles des calculatrices analogues et digitales. Il est ensuite tenu compte des conditions d'emploi de ces machines dans les établissements de recherche nucléaire.

La Construction des Instruments Electroniques Exposés aux Radiations (page 251)

Pye Ltd., effectue de nombreuses recherches sur le comportement sous radiations de divers instruments électroniques. L'effet des neutrons thermiques et rapides, des rayonnements beta et gamma, des produits de fission est étudié pour des installations de réacteurs en fonctionnement. Certains dégâts sont permanents, d'autres cessent en mème temps que l'irradiation. Le constructeur a deux problèmes principaux à résoudre: (a) L'équipement doit fonctionner à coup sûr dans un milieu irradié; (b) Les matériaux utilisés pour la construction de l'équipement ne doivent pas entraver l'utilisation du réacteur.

Fehlerquellen in den Instrumenten (Seite 241)

Durch das alles überragende Erfordernis nach absoluter Sicherheit wird die Tendenz zu falscher Information verstärkt, die dann die Ursache wird, Reaktoren stillzusetzen. Wenn dies auch nicht von grosser Bedeutung ist bei Forschungs-Reaktoren, so kann es sehr kostspielig werden, wenn Leistungs-Reaktoren unnötig stillgesetzt werden. Um eine Uebersicht über die verschiedenen Ursachen von Instrumenten-Fehlern gewinnen zu können, die bei Reaktoren gefunden wurden, die mindestens ein Jahr bereits in Betrieb gewesen sind, hat Nuclear Engineering eine Untersuchung durchgeführt, die zeigt, dass man darauf achten muss die Zuverlässigkeit von elektronischen Einrichtungen zu erhöhen, insbesondere von Gleichstrom-Verstärkern, ferner von Kraftversorgungs-Anlagen, Kabelverbindungen und der Unterhaltung von Relaynetzen. Die Folgerungen, die man daraus zu ziehen hat, werden ebenfalls diskutiert.

Automatischer Schutz bei gasgekühlten Reaktoren (Seite 243)

Da die Temperatur, die die Brennstoffelemente in einem gasgekühlten Reaktor erreichen, auf dem Unterschied zwischen Wärmeerzeugung und Wärmeentnahme beruht, besteht das Problem der Kontrolle in der Hauptsache darin zu vermeiden, dass das Gleichgewicht des thermischen Zustandes soweit gestört wird, dass die Brennstofftemperaturen zu hoch steigen und dadurch Spaltungsprodukte freiwerden. Um einen voll wirksamen automatischen Schutz zu erzielen, muss eine Anzahl von veränderlichen Werten in Rechnung gezogen werden, zu denen der Fluss, die Periode, die Strömung, der Druck und die Gas-Temperaturen gehören.

Das Messen des Neutronenflusses bei erhöhter Temperatur (Seite 245)

Die Reihe von Reaktoren, die den Magnox Werken folgen sollen, macht es nötig Detektoren zu haben, die imstande sind, bei hohen Temperaturen zu arbeiten. Ionisationskammern, die bei 400°C. benutzbar sind, und Spaltungszähler, die bis zu 900°C. noch brauchbar sind, werden zur Zeit gemacht, und es ist möglich über diese Grenzen noch weiter hinauszugehen.

Der Zweck der Rechenanlagen (Seite 248)

Eine Organisation, die dabei ist eine Rechenanlage zur Anwendung bei Forschungsarbeiten zu beschaffen, kann in die Versuchung geraten eine Anzahl von Einheiten miteinander zu verbinden, die voneinander unabhängig sind, weil möglicherweise Kosten gespart werden. Der Aufsatz unterzieht die mehr wesentlichen Charakteristiken von Analogie- und Ziffern-Rechenmaschinen einer Prüfung mit besonderer Berücksichtigung ihrer Benutzung in Kernkraft-Anlagen.

Strahlung und die Konstruktion elektronischer Anlagen (Seite 251)

Weitreichende Forschungen über die Wirkung der Strahlung auf die Komponenten elektronischer Einrichtungen sind von der Firma Pye Ltd. durchgeführt worden. In Betriebs-Reaktoren wird die Apparatur schnellen und thermischen Neutronen, Gamma-, Beta-Strahlen und Spaltungsbruchstücken ausgesetzt. Gewisse Schäden bleiben, andere sind nur merkbar während der Bestrahlung. Der Konstruktör steht einer doppelten Aufgabe gegenüber: (a) sicher zu gehen, dass die Anlage weiter richtig arbeitet trotz der Bedingungen, (b) dass die Materialien, die bei der Konstruktion Verwendung finden, den Betrieb des Reaktors nicht ungünstig beeinflussen.

Origen de Faltas en la Instrumentación (pág 241)

Debido a las dominantes exigencias de seguridad a todo costo, la tendencia de que información espuria sea motivo de las paradas de reactores va aumentándose. Mientras que estas paradas puede que no sean de gran importancia en los reactores de investigación, la parada innecesaria de reactores de fuerza puede resultar costosa. Para obtener una estimación de las diversas causas habidas en reactores que han estado operando durante por lo menos un año de faltas de instrumentación, Nuclear Engineering ha llevado a cabo un examen que demuestra que se debe prestar atención al mejoramiento de la calidad confiable de los aparatos electrónicos, particularmente los amplificadores de corriente continua, la provisión de abastecimientos de fuerza, encablado y el diseñado y mantenimiento de redes de relais. Las implicaciones de estos resultados también se discuten.

Protección Automática Para un Reactor Enfriado Por Gas (pág 243)

Como la temperatura obtenida por elementos de combustible en un reactor enfriado por gas depende de un equilibrio entre la generación de calor y la extracción de calor, el problema principal de control es el evitar una condición de desequilibrio en el estado térmico, de modo que las temperaturas del combustible no se eleven lo suficiente para motivar una liberación de fisión. Para que surta máximo efecto, la protección automática debe tener en cuenta diversos variables, incluyendo flujo, periodo, corriente, presión y temperaturas de gases.

Medicion de Flujo Neutronico a Elevadas Temperaturas (pág 245)

La serie de reactores que deben seguir las centrales Magnox exigen detectores capaces de funcionamiento a altas temperaturas. Se están haciendo actualmente cámaras de ionización para uso a 400°C. y contadores de fisión para uso hasta 900°C. y es posible que haya una extensión adicional de estos límites.

El Objeto Del Computador (pág 248)

Una organización que está por comprar un computador para ser aplicado a labores de investigación podría ser inducida a enlazar en conjunto una cantidad de unidades que no tengan relación una con la otra debido a una posible economía en el costo. Este artículo examina algunas de las más pertinentes características tanto de máquinas análogas como digitales, con especial referencia a su empleo en establecimientos de energía nuclear.

Irradiacion y Diseño Electronico (pág 251)

Una gran cantidad de investigaciones ha sido llevada a cabo por Pye Ltd. sobre el efecto de irradiación en componentes electrónicos. Los reactores operacionales someten equipo a la neutrones rápidos y térmicos, rayos gama, beta y fragmentos de fisión. Alguna parte de la avería es permanente y alguna parte persiste únicamente durante la irradiación. El diseñador tiene que enfrentar una tarea doble: (a) asegurar que el equipo continúe funcionando apesar de las condiciones y (b) que los materiales usados en la construcción no afecten adversamente el funcionamiento del reactor.

Technical Papers and Publications

American Society of Mechanical Engineers

(Metals Engineering Division, at the ASME-AWS Metals Engineering Conference, Los Angeles, April 25-29)

60-MET-5. Nickel-Chromium-Iron Alloy (Inconel) Forgings for Reactor Systems. C. L. Dotson and R. L. Roshong Cameron Iron Works, Inc.).

By the use of multiple-ram forging presses, it is possible to produce forgings having ultimate strength levels as high as 90,000 p.s.i., and yield strengths of 45,000 p.s.i., as against 80,000 and 28,000 in comparable sections produced by conventional methods. Forging properties of the alloy are discussed, and there is a description of the production of three components—a 14 in. gate valve body and its bonnet and a control guide and support, the largest of which weighed 3,150 lb. It is pointed out that Inconel presents forging difficulties because of its high strength at elevated temperature, and that the mechanical properties can be controlled by proper die design to provide the necessary amount of hot working during forging. Controlled thermal cycles after forging, variation of the carbon content of the alloy, and low sulphur content of the heating fuel, are all important factors.

60-MET-6. Arc Welding of a Ni-Cr-Fe (Inconel) Alloy for Nuclear Power Plants. Jay Bland and W. A. Owczarski (Knolls Atomic Power Laboratory, General Electric Co., Inc.).

An investigation into the welding of Inconel, now being seriously considered for reactor work because of its superior stress-corrosion properties, compared to the austenitic stainless steels. The tests covered commercially available filler metals and the shielded metal arc, inert gas tungsten arc, and inert gas metal arc processes. In general, all welds of Inconel to itself, to 304 stainless steel, or to carbon steel failed in the weaker base metal under static tensile tests. Mechanical properties of the all-weld-metal Inconel fillers exceeded those of the annealed wrought base metal.

60-MET-7. Fabrication of a One-Inch Thick, Ten-Inch Diameter Welded Inconel Pipe. W. L. Fleischmann (Knolls Atomic Power Laboratory) and R. F. Gurnea (Midwest Piping Co., Inc.).

A description of the formation of a thick Inconel pipe formed from flat plate, and gives the mechanical and metallurgical data on specimens. Two weld processes were used; the TIG (tungsten arc inert gas shielded) and the MIG (metal arc, semi-automatic inert gas shielded). It is stated that the TIG process, with coated electrodes produced sound welds, but that there is evidence that some quality in the base metal adversely affects the quality of MIG welding, fissuring being observable in the heat-affected zone. Nuclear quality weldments can be produced by this process but, owing to the difficulties of interpreting radiographs to water-clear standards, the TIG process is preferred.

60-MET-9. Brittle Fracture Characteristics of a Reactor Pressure Vessel Steel. E. T. Wessel and W. H. Pryle (Metallurgy Department, Westinghouse Research Laboratories).

Comparison of the characteristics of a 7 in. thick plate in both the " as-received " (normalized) condition and after thermal cycling to represent the fabrication processes of a PWR pressure vessel (cladding, normalizing after cladding, and stress-relieving after welding). The steel was ASTM A302 Grade B, with a chemical analysis of 0.21 C, 1.34 Mn, 0.015 P, 0.01 S, 0.27 Si, 0.04 Ni, 0.09 Cr, 0.5 Mo, 0.08 Cu.

Although the heat treatment slightly increased the notch-sensitivity, as well as raising the transition temperature, this steel was found to be considerably more resistant to brittle fracture than other steels tested under similar conditions. Average applied stresses of above the normal yield strength were required to cause fracture in the A302B steel, even with an existing crack, at temperatures above −150°F, while other steels fractured—at considerably higher temperatures—at a fraction of the yield strength. The cautious statement is made, however, that it is not known whether the same results would be obtained with specimens of different size, owing to possible variation in size effects in different steels.

U.S. AEC

Survey of Industrial Requirements for General Testing Reactors for the period 1960-1965. Prepared by Staff of Division of Reactor Development, Atomic Energy Commission.

In order to be able to estimate the test reactor programme, a questionnaire was sent, in August, 1959, to 185 U.S. manufacturing companies, asking them to give their estimated loop and capsule irradiation requirements for the next five years, classified as to diameter of hole required, length of time, flux density and (possibly most important) whether the requirements were " firm, " " less firm " or " speculative."

Of the 185 companies approached, 110 replied but, as far as can be judged, only 28 companies indicated their requirements in

(*Continued on page* 276)

The Transportation of Radioisotopes*

THE rapid development of applications for radioisotopes has led to special regulations being drawn up by the principal organizations concerned in their transportation.

The current or pending United Kingdom regulations (January, 1960) for the carriage of radioisotopes by the various forms of public transport are as follows:—

POST.—G.P.O. Regulations (these are under revision).

ROAD.—Ministry of Transport Regulations under the Radioactive Substances Act, 1948 (awaiting Ministerial approval).

RAIL.—British Railways Conditions of Carriage for the Conveyance of Radioactive Substances (these have been lodged with the Ministry of Transport and are awaiting approval).

SEA.—The Merchant Shipping (Dangerous Goods) Rules, 1952. The precise requirements are detailed in the report of the Standing Advisory Committee on " The Carriage of Dangerous Goods and Explosives in Ships."

PORTS AND HARBOURS.—A Ministry of Transport code of practice is in preparation and will be used as a model for Port Authority regulations.

AIR.—The International Air Transport Association Regulations relating to the carriage of restricted articles include a section on radioactive materials.

The International Atomic Energy Agency in Vienna is at present drawing up overall recommendations for the transport of radioisotopes by land, sea and air. These proposals have already had some effect on the new draft regulations in the United Kingdom. There already exists an International Convention concerning the Carriage of Goods by Rail, and an annexe sets out the conditions for the transport of radioactive materials on international rail routes.

A package is exempt from regulations if it contains less than specified amounts of radioactive material, and the dose rate on the surface is less than 10 mr/24 h.

* From a paper presented by Mr. G. R. Newberry, manager, Physics Department, Radiochemical Centre, U.K.A.E.A. at the Royal Society of Health Congress at Torquay on April 25, 1960.

detail. (It should be realized that irradiation to be performed under Commission contract was not to be noted.) This report analyses the replies received, in some detail (10 tables). Briefly, it would appear that the loop test requirements for the five-year period will total 549 (of which 238 are speculative and only one is classified as firm) while the total for capsule tests is 1,609, including 126 firm and 1,021 speculative.

TID-7580. Proceedings of the 1959 Symposium on Low Temperature Nuclear Process Heat. (Office of Technical Services, Washington 25, D.C., $0.75.)

This report of proceedings of a symposium held by the AEC at Germantown, Maryland covers results of surveys of U.S. process heat requirements, technical and economic factors peculiar to low-temperature process heat reactors, details of reactor studies, history, objectives and programme of various experimental reactors and a bibliography. Held before an audience containing some 200 representatives of industry, the report also contains a summary of discussions.

TID-3529 (1st Rev.). Reprocessing of Irradiated Fission Reactor Fuel and Breeding Material. Literature search compiled by James M. Jacobs (Office of Technical Services, Washington 25, D.C. $1.25).

A bibliography of over 360 references to unclassified reports received by the Technical Information Service since the issue of TID 3312 some time ago. Cost of the material and availability in photostat or microfilm form are indicated, where applicable.

TID-3088. Boiling Water Reactors—Annotated Bibliography of Selected Literature. Compiled by James M. Jacobs (Office of Technical Services, Department of Commerce, Washington 25, D.C. $1.50).

In this, more than 250 references to unclassified reports and published information covering all aspects of the development of boiling water reactors, both heterogeneous and homogeneous. U.S. (both AEC and private companies), British and European material is included, and each reference has a short summary of the report or article. Subject and author indexes are included, as well as an indication of availability.

Radioisotopes in Science and Industry. Special report of the AEC (Superintendent of Documents, Government Printing Office, Washington 25, D.C. $1.25).

A general (i.e., semi-technical) report summarizing the Commission's isotope development programme, the uses of isotopes in agriculture and medicine, new applications, training programmes for utilization, production and safety. Appendices include information on distribution, a list of appropriate films and the Commission's regulations relating to radiation and isotope usage.

SL-1674. Power Cost Normalization Studies, Civilian Power Reactor Programme. (Office of Technical Services, Washington 25, D.C. $2.50.)

Capital and operating cost studies for eight power reactor concepts—pressurized water; boiling water; organic cooled; sodium graphite; fast sodium cooled; aqueous homogeneous; heavy water; gas cooled. The scope of work in connection with the studies and basic parameters are discussed, also breakdowns and summaries of capital costs, fuel cycle estimates, and operation and maintenance costs. This information is presented in 164 pages of text, tables and graphs, with 102 double-page pull-out drawings.

The Institution of Mechanical Engineers

An Approximate Analysis giving Design Data for Corrugated Pipes. P. J. Palmer, M.Sc., Ph.D. (Chief Engineer, John Thompson (Wolverhampton), Ltd.).

The method of analysis given in this paper is suitable for calculating the extensions and stresses in corrugated pipes of the type in which the radius of corrugation is constant, and is applicable to corrugations of any included angle. Both extensions and stresses are given for five particular angles. Stresses and deflections arising from end load, bending moment, and pressure, may readily be deduced by this method, which gives fair accuracy.

AEA

AERE—C/R 2853. Chemical Investigations in High Temperature Water Loops. J. K. Linacre and H. Morley (Harwell). (H.M.S.O., 17s.)

Describes work carried out in mild steel and stainless steel loops, operating at 260°C (500°F) with water of pH 10-11. In corrosion experiments on the mild steel loop, it was found that the corrosion rate (determined by the rate of change of hydrogen concentration) of a loop previously cleaned by acid pickling, fell rapidly after 300 h, to about 1/10 its initial value. Uncleaned, and initially covered by a layer of low temperature oxide, the initial corrosion rate was less than that for the clean steel, but the rate of release of corrosion products was greater by a factor of 10, even after 300 h exposure.

AEEW-R28. The Analogy between the Bubbling of Air into Water and Nucleate Boiling at Saturation Temperature. G. B. Wallis (Reactor Development Division, Winfrith). (H.M.S.O. 3s.)

In studying the behaviour of water boiling, it should be possible to separate thermodynamic and hydrodynamic effects and study the hydrodynamic aspects by a gas-liquid analogue in which air is bubbled through a porous medium to represent the generating surface. This report presents a case for such an analogue, and describes and analyses points of similarity and equivalent behaviour.

AERE-R 3085. Some Effects of Radiation in Cast Epoxide Resin Systems. I. D. Aitken and (Miss) K. Ralph (Engineering Division, Harwell). (H.M.S.O. 4s. 6d.)

An investigation into changes in the flexural strength of various forms of cast epoxide resins, with in-pile irradiation, and the variation in results obtained with different types of curing agent.

I.G. Information Series 68 (RD/CA). Bibliography on Gas Temperature Measurement. By E. McCoy (H.M.S.O. 1s. 9d.).

This bibliography on the measurement of gas temperature is divided into eight sections, classified by subject. In addition to the general question of temperature measurement and miscellaneous material, there are sections devoted to resistance thermometry, spectral methods, temperature probes, thermocouples, pyrometers, and the problems of temperature measurement in flowing gases.

I.G. Information Series 72 (RD/CA). Bibliography on Pumps for Corrosive Liquors. E. McCoy (R. and D. Capenhurst). (H.M.S.O., 1s. 9d.)

A bibliography of published work and patent specifications, classified under four heads: general corrosion problems in chemical and allied industries, methods and operation, materials and construction, pumping of mine and well waters, and corrosion of pumps employed on this service.

MEETINGS

May 24.—Society of Instrument Technology, 20 Queen Anne St., London, W.1. Annual General Meeting and Presidential Address. 6 p.m.

May 25.—The Institution of Electrical Engineers (Electronics and Communications Section). Discussion on "New Semiconductor Devices and their Possible Applications," opened by A. F. Gibson, Ph.D., and G. King, B.Sc.(Eng). 5.30 p.m.

May 27.—Non Destructive Testing Society (Reid Knox Hall, British Institute of Radiology, 32 Welbeck St., London, W.1). "Site Inspection on Overseas Projects," C. C. Bates.

May 27.—The Institution of Chemical Engineers (at the Imperial College of Science and Technology, London, S.W.7). 3.30 p.m. Colloquium on "Heat Transfer to Liquid Fluidized Beds and to Coarse Suspensions flowing in a Vertical Pipe." J. W. Smith.

May 30-June 2.—British Electric Power Convention, Bournemouth.

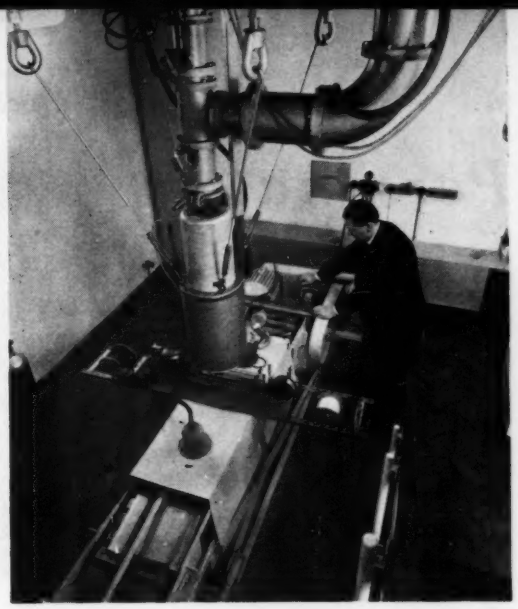
June 2.—The Institution of Chemical Engineers (at the University of Sheffield). 3 p.m. "An improved approach to certain heat transfer problems; finned tubes in nuclear reactors; natural convection and radiation from conducting surroundings." Prof. Burnay (University of Liège).

June 3.—The Institution of Chemical Engineers (at the Imperial College of Science and Technology, London, S.W.7). 3.30 p.m. Colloquium on "Mass Transfer in Liquid-liquid Systems." N. G. Maroudas.

June 5-9.—World Power Conference (Sectional Meeting), Madrid.

June 9.—The Institution of Mechanical Engineers. 5.30 p.m. Annual General Meeting.

Industrial Notes



A view of the 2 MeV Van de Graaff accelerator at the new Standard Telecommunications Laboratories recently opened at Harlow in Essex.

Mitchell Construction have been awarded a contract by the AEA for the construction of a second primary separation plant at Windscale. Work is to commence immediately and is expected to take three years to complete. The plant will service fuel elements from the new power stations.

A new fully automatic copper rod rolling mill is now operating at the **BICC** works at Prescot. Costing £1,500,000, the No. 4 Rod Mill has a total floor area of 72,000 sq. ft and is capable of a production of 100,000 tons a year. The mill was designed in collaboration with **Brightside Foundry and Engineering** and installed by BICC, but most of the construction work was carried out by **Sir Alfred McAlpine.**

ICI report that Terylene reinforcement is being used in the ¼-in. inside diameter Neoprene hose used in the water-cooling circuit for the magnet coils of the 7 GeV proton synchrotron, Nimrod, at Harwell. **Castle Rubber** are producing the hose in 60-ft lengths tested to a pressure of 300 lb per sq. in.

Wakefield-Dick Industrial Oils have been selected by the **CEGB** to supply lubricants for the 550-MW nuclear power station to be constructed at Dungeness.

Babcock and Wilcox have produced a film entitled "Goliath," describing the design and construction of the largest Goliath-type crane in the world. Built at their Renfrew works, the crane is for the Hinkley Point power station and has a span of 250 ft, is 250 ft high and capable of lifting 400-ton loads to a height of 200 ft.

Two data-processing units are being supplied by **English Electric** to the Windscale works of the U.K. AEA. The first, now nearing completion, is for temperature monitoring on HERO and scans some 1,250 thermocouples, giving automatic alarm and print-out of any temperature that is beyond limits.

A new instrumentation panel containing seven strip chart recorders has been installed on the BEPO research reactor at Windscale. The multiple pen instruments give a permanent record of graphite temperatures and were supplied by **Honeywell Controls.** The panel also includes 12 Bailey trip amplifiers.

A contract has been awarded to **Mitchell Engineering** for the supply of a boiler for emergency applications at Windscale. The boiler is a 66,000 lb/hr evaporation type automatically controlled and is fired by four Hamworthy type 16F pressure jet burners. A self draining Melesco super-heater is employed.

Vokes recently held an exhibition of their products at the Kensington Palace Hotel, London.

A dust-free area for the assembly of special valves and automatic fluid control equipment for nuclear work has been built by **Fisher Governor,** a member of the **Elliott-Automation Group.** The special air-conditioning plant cleans and controls the air humidity and temperature to close limits.

A joint research programme has been announced by **A. Reyrolle, C. A. Parsons** and **AEI.** The programme provides for the exchange of technical information and experience in the field of generating plant and associated equipment. The three companies will continue to trade in competition, however.

Film Cooling Towers have been awarded a £600,000 contract for the supply of three, 4,800,000 gallons an hour, natural draught cooling towers for the Thorpe Marsh Power Station.

Ether Langham Thompson (Italiana) is the name of a new company in Milan to manufacture and market the products of Ether Langham Thompson and subsidiary companies.

Dewrance recently held a private exhibition of Dewrance valves and mountings; electrical valve actuators manufactured by their subsidiary company **Jones Tate** of Bradford; Dewrance-Asco solenoid-operated valves, and Microsen electronic control gear manufactured under licence from **Robertshaw-Fulton Controls** of U.S.A.

APV celebrate their fiftieth anniversary on June 10.

Dunlop Rubber Australia and **Oldham and Son** of Manchester announce the formation of a new company, **Dunlop Oldham,** for the marketing of the Oldham PG double-sleeve tubular traction and other industrial batteries in Australia.

Parsons Powergas is the name of a concern formed by **Ralph M. Parsons** of Los Angeles and **P.G. Engineering** for the complete engineering and construction of petroleum, petrochemical and related plants.

Winston Electronics have associated with **Dynamics Corporation** and intend doubling the size of their production facilities.

Pye and **Sciaky Electric Welding Machines** announce the formation of an Australian company for the manufacture of Sciaky resistance welding machines. A £100,000 factory will be built at Fairfield, N.S.W.

The fifth **International Instruments and Measurements Conference** will be held in Stockholm from September 13-15. The conference is organized by the Royal Swedish Academy of Engineering Sciences and the Swedish Association of Technical Physicists.

ASTRA of Raleigh have been retained by **Carolinas Virginia Nuclear Power Associates** as nuclear consultants for the construction of the 17 MW pressurized water pressure tube type power station.

Atomics International have formed two new departments, a compact power systems department and a reactor physics and instrumentation department.

Brooks Rotameter have constructed a new manufacturing and engineering facility at Scarborough, Ontario.

The first international **Compressed Air and Hydraulics Exhibition** and the second **European Fluid Power Conference** was held at Olympia from April 25-29. More than 120 companies participated, including 26 from overseas.

In the annual report of **W. R. Grace** the president, Mr. J. P. Grace, states that greater clarity and shrink energy of irradiated polythene film has been achieved by the bombardment by electrons at up to two million volts. The film is being produced at the Crayovac Simpsonville plant in South Carolina.

Recent changes and new addresses are:

Ransome and Marles' Leicester office is now at 223 Belgrave Gate.

Fairey Aviation are now at Woodlands Park, Iver Heath, Bucks. Tel: Uxbridge 8377.

Atomics International are now at 8,900 De Soto Avenue, Canoga Park, Cal.

Precision Components (Barnet) have moved to Kabi Works, Cranborne Road, Potters Bar. Tel: Potters Bar 3444.

The Glasgow office of the alloys division of **Union Carbide** have moved to Cornhill House, 144 West George Street. Tel: Douglas 7753.

ICT's new computer centre is at Putney Bridge House.

The **Continental Connector Division** of **Ultra Electronics** have moved to Industrial Estate, Long Drive, Greenford, Middlesex. Tel: Waxlow 5721.

Personal

Mr. J. F. Willsher.

Mr. M. L. Jofeh.

Mr. R. S. Stiff.

Mr. P. A. Charman.

Appointments

Mr. J. Pears as a part-time member of the AEA. **Sir Alan Hitchman** to assume the duties of **Sir Donald Perrott** who is retiring. Sir Alan will retain his existing responsibilities.

Mr. B. Topley as deputy-chairman of Albright and Wilson.

Mr. M. L. Jofeh as an additional director of Sperry Gyroscope.

Mr. J. F. Holman as managing director of Holmes Brothers.

Mr. C. H. Offord to the board of Honeywell Controls.

Mr. W. R. Timken as president of Timken Roller Bearing.

Mr. C. J. Atkins and **Mr. F. W. Goodge** as joint managing directors of Keith Blackman.

Mr. N. A. Iliff as managing director of Shell Chemical Company. **Mr. J. L. Black** as general manager of Shell Haven refinery.

Mr. R. S. Stiff as sales manager of Nuclear Enterprises.

Mr. J. F. Willsher to the board of George Kent.

Sir Edwin Herbert as president of the Electrical Development Association for 1960-61, **Lord Morrison** as vice-president, **Capt. J. M. Donaldson, Sir Harry Railing** and **Mr. V. W. Dale** have been reappointed vice-presidents, **Mr. D. B. Irving** as chairman of the Council and **Mr. R. B. Brown** as vice-chairman.

Mr. P. A. Charman as sales development manager of Semiconductors.

Mr. E. A. Ward as company secretary of Lancashire Dynamo Electronic Products.

Dr. C. Dannatt, as vice-chairman of AEI. **Mr. H. West** as managing director of AEI (Manchester).

Mr. E. W. Molesworth as chief engineer of G.E.C.

Mr. S. Farrer as managing director of British Furnaces.

Mr. J. Bell to the board of M.O. Valve Company, a subsidiary of G.E.C.

Mr. H. J. N. Nethersole to the board of Vulcan Foundry and Robert Stephenson and Hawthorns.

Mr. W. G. Mitchell as president of the Federation of Civil Engineering Contractors. **Mr. A. J. Hill** as chairman, and **Mr. P. W. E. Holloway** as vice-chairman.

Mr. H. E. R. Shand to the board of Mullard.

Mr. J. E. Whitaker as sales manager of Hagan Controls.

Mr. D. Lindsey as general manager of Williams and James (oil tools). **Mr. A. Gleave** as general sales manager, and **Mr. P. A. Moffat** as deputy sales manager.

Mr. R. Eliason to the board of Nissen Steelworks.

Dr. P. R. Howard as head of the high-voltage laboratories of the CEGB research laboratories at Leatherhead.

Mr. J. W. Charnley and **Mr. J. J. G. Michie** to the board of John Laing and Son.

Mr. R. A. Cabell, Mr. A. P. Gagnebin, Mr. R. H. Waddington and **Mr. J. C. Parlee** as vice-presidents of International Nickel.

Mr. H. V. Slade and **Dr. G. A. V. Sowter** have been re-elected chairman and vice-chairman of Radio and Electronic Component Manufacturers. **Mr. C. M. Benham** has been re-elected treasurer.

Mr. L. G. Oxford as president of the South Wales branch of National Union of Manufacturers.

Mr. C. J. Williams as general sales manager of the newly formed Optoshield.

Overseas

Danatom appointments are: **Mr. O. Christiansen,** president; **Mr. J. Moller,** vice-president of the Council. Chairman of the executive committee **Mr. T. Franck** and vice-chairman **Mr. E. W. Lund.**

Dr. H. Hardung-Hardung in charge of the European Nuclear Energy Agency's economic office.

Mr. J. B. Adams as interim director-general of CERN following the death of Prof. C. J. Bakker. Mr. Adams was recently appointed director of the new fusion research laboratory at Culham, U.K., but will remain with CERN until later this year.

Dr. R. F. Peters as medical officer of the *Savannah*.

Dr. A. M. Weinberg.

Dr. W. H. Zinn.

Mr. D. W. Jefferson-Loveday, as chairman of an I.A.E.A. Panel on Safe Operation of Critical Assemblies and Research Reactors.

Mr. K. Van Walvaren as sales supervisor for Wolf Electric Tools in Holland.

Dr. M. P. Hnilicka as scientific assistant to the vice-president and director of research for the National Research Corporation.

Mr. L. T. Tischer as assistant manager of contract sales of Tracerlab.

Mr. R. W. Ayers and **Mr. D. Sciaky** to the board of Sciaky Electric Welding Machines, Australia.

Mr. J. F. Stolz as project engineer for modifications for the OMRE, Idaho.

Dr. A. R. Matheson as sales manager, nuclear fuels department of Spencer Chemicals.

Awards

Dr. A. M. Weinberg and **Dr. W. H. Zinn** the Atoms for Peace Award for 1960.

Mr. W. D. Hamilton a 1960-61 CIBA Fellowship Trust to study nuclear physics in Yugoslavia.

Obituary

Nuclear Engineering regret to report the deaths of the following:—

Prof. C. J. Bakker, director-general of CERN, at the age of 56, in an aeroplane accident near Keansburg, New Jersey, U.S.A., on April 25. Prof Bakker was Dutch.

Mr. J. R. MacCabe, senior information officer at CERN, on April 17 at the age of 46.

Prof. M. von Laue, director of the Max-Planck Institute of Physical Chemistry, in April at the age of 80.

Mr. W. M. Grainger, director and secretary of Walter Somers, on May 10.

Retirements

Mr. J. W. Millray as general manager of Thos. Ward.

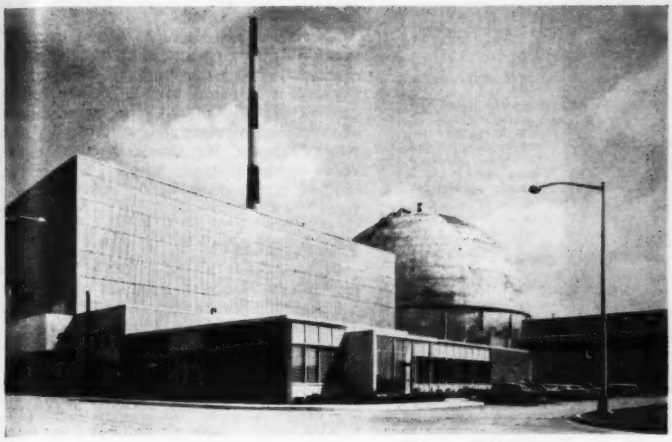
Mr. N. W. Warsop from the board of Warsop Power Tools.

Tours

The Duke of Edinburgh of CERN, Geneva.

Mr. J. McCone chairman of the U.S.AEC, of nuclear centres in France.

Mr. J. A. Jackson, works director of Wolf Electric Tools, of Canada during May.



The 180 MW boiling water Dresden nuclear power station, 50 miles south-west of Chicago. Designed and built by General Electric for the Commonwealth and Nuclear Power Group the plant has now supplied electricity to the Commonwealth Edison customers in northern Illinois.

World News

International

AN OFFER by the U.S. for the supply of $200,000 worth of equipment has been accepted by the IAEA in order to meet requests from member States for technical assistance. Under the offer of assistance to the agency the U.S.AEC has stated that specific proposals for equipment must be reviewed and approved before the equipment is shipped.

A PRELIMINARY ASSISTANCE mission has left the IAEA for the Sudan, Ivory Coast, Federation of Mali, Morocco, Tunisia and Greece. This is the fifth mission of its kind to be sent out by the Agency. Mr. J. Webb, acting director of the division of technical supplies, is in charge.

A DECISION has been made by the Board of Governors of the IAEA to submit to the General Conference for consideration and appropriate action, a document on principles and procedures for safeguards against military use of material and facilities made available through the Agency. The principles and procedures can also be applied to bilateral or multilateral arrangements at the request of the parties concerned or to activities in any one State at the request of that State.

A THIRD WING is being added to the PS laboratories at CERN and new borings have been made at Peney, near the Rhone River, in an attempt to double the supply of refrigeration water.

A FIVE-DAY SEMINAR on codes for reactor computations was held in Vienna during April by the IAEA. Twenty countries were represented by more than 100 delegates. Discussions indicated how computing machines could be more widely and effectively used for calculations of the design and operation of reactors.

TWO SITES for the European University at Florence have been surveyed. Financial steps are to be taken to ensure opening of the University by the autumn of 1961.

United Kingdom

A NEW LABORATORY has been opened by Lord Hailsham at the isotope research centre at Wantage. The laboratory incorporates an automatic gamma irradiation processing plant which will be put into service some time this month. The plant will enable industry to make full-scale trial runs of irradiation processes. Designed to house half a million curies of cobalt-60 the plant now holds 150,000 curies costing about £50,000 (see *Nuclear Engineering*, Nov., 1959, p.410).

DISCUSSIONS have taken place at Risley between the AEA and Euratom on the advanced gas-cooled reactor. Fifty members of Euratom were present, headed by Mr. P. Caprioglio, and lectures were given by British, French, German and Italian speakers.

AN INTERNATIONAL reactor course is to be held at Harwell from July 4-15 and will be attended by 48 technicians from OEEC and Euratom countries. The course is designed to give senior executives who have a technical background an introduction to the principles and problems of nuclear science and engineering.

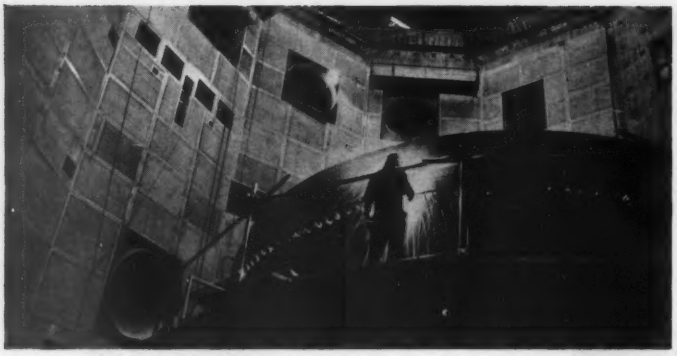
NO ANNEALING of the graphite stacks in the British civil reactors will be required in their first 20 years of operation, Sir John Cockcroft stated in Milan.

BRITISH ELECTRIC POWER CONVENTION, the twelfth in the series, will take place in Bournemouth from May 30-June 2.

Brazil

PURE URANIUM of a grade suitable for use in nuclear reactors has been produced by scientists at the University of Sao Paulo.

Dr. D. W. Fry, director of Winfrith presenting a silver trowel to Dr. S. Eklund of Sweden who is chairman of the DRAGON board of management at the inauguration ceremony on April 27.



The first spherical course being welded to the pressure vessel skirt in No. 2 reactor at Hinkley Point.

Denmark

THE SECOND CORE LOADING for the DR 2 research reactor at Riso will be supplied by Babcock and Wilcox, U.S. The core, consisting of 30 fuel elements and 10 control elements of 90% enriched uranium, will be shipped during June. The elements for the 5MW, tank-type reactor are of the pinned type of aluminium construction.

France

CO-OPERATION ON RESEARCH into radiation sickness and cancer is to be undertaken by France and Russia. The two countries recently signed an agreement for co-operation in the peaceful uses of nuclear energy.

West Germany

THE PROPOSAL to convert the Esso-Bolivar oil tanker into a nuclear-powered vessel has been turned down by the Federal Government on economic grounds. It is now thought that it will be more practical to build a new ship of about 15,000 tons for one of the three reactors now under development. This decision is likely to prolong the time of completion of Germany's first nuclear powered hull until at least 1963.

A WASTE DISPOSAL SITE has been chosen for radioactive materials in Bavaria. Work is expected to begin on the site some time this year and it is expected to cost about 415,000 DM.

THE NEW BUILDINGS for the Institute of nuclear fusion at Stetternich near Jülich are complete and are being occupied.

India

THE CANADA - INDIA REACTOR under construction at the Atomic Energy Research establishment at Trombay is expected to begin operating this time next year according to the project manager, Mr. N. B. Prasad. The reactor is a 40 MW NRX-type.

A COMPREHENSIVE TOUR of West German nuclear establishments has been undertaken by Dr. H. J. Bhabha, head of the Atomic Energy Commission.

Italy

FULL POWER was reached by Ispra 1, the 5MW heavy water tank-type reactor, on April 16. The second core with high enrichment is expected to be loaded shortly.

AN AGREEMENT for nuclear fuel development has been signed by CNRN with Allis-Chalmers of the U.S. The agreement calls for an investigation of the uranium thorium fuel cycle; a development programme which CNRN will carry out with Allis-Chalmers and Italian industry. This will include the design, construction and operation of an integrated uranium thorium fuel element and a pilot reprocessing plant to be built in Italy.

MAIN SUB-CONTRACTORS for the SENN project have been named. They are: Terni (pressure vessel); Neratoom, Holland (heat exchangers); Franco Tosi (steam separators); and Steel Mills of Brescia; Cornigliano and Terni (the spherical container for the reactor); Ansaldo (condenser and turbo generator); Italstrade (all civil engineering work). Other subcontracts are still to be negotiated.

AN ANTI-SIGMA plus particle is reported to have been discovered by scientists at the Rome University Institute of Physics. The particle was detected in a nuclear reaction produced in nuclear emulsions irradiated with a beam of antiprotons.

PRELIMINARY EXPERIMENTS are reported to be under way with the 50 kW aqueous homogeneous-type reactor at the Enrico Fermi Nuclear Studies Centre. The reactor, built by Atomics International, recently became critical.

Japan

AN INDUSTRIAL LEADER has recently stated that Japan plans to start building an experimental nuclear powered ship within the next two years. Mr. T. Shaurai, president of the Mitsubishi Company, made the statement on a recent tour of Australia and New Zealand. He also claimed that the vessel would be ready within 10 years but did not give any indication of the size or type.

Pakistan

PLANS ARE BEING CONTINUED to establish a National Institute of Nuclear Sciences and Technology near Rawalpindi. The centre will have a research reactor. Two nuclear research centres for the fields of research in agriculture, medicine and industry have also been planned for Lahore and Dacca and equipment has been ordered from abroad.

Poland

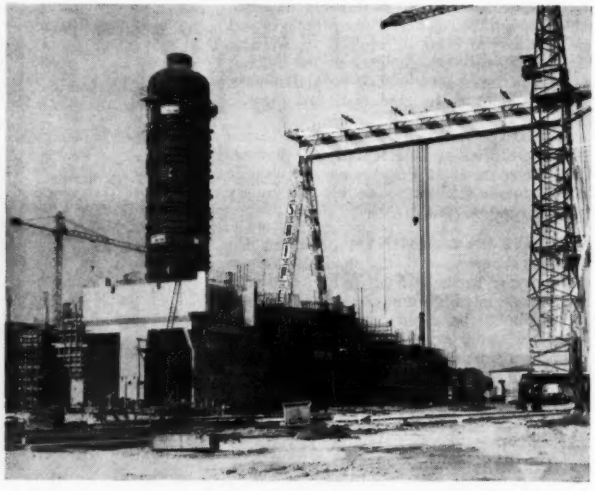
IT IS BELIEVED that construction of the first nuclear power station, previously scheduled for 1966, has been postponed until 1970. It is also understood that construction of a nuclear ship will now not begin before 1970 but an experimental reactor for ship propulsion will be built in the next five-year plan. Investment on nuclear energy will be some 20% of the next five-year plan which will make it possible to build a new experimental reactor in Cracow.

Puerto Rico

THE CONTRACT for the nuclear portion of the 16.3 MW nuclear power station has been awarded to Maxon Construction. Estimated cost of the conventional turbogenerating equipment, exclusive of the site, switchgear and transmission facilities, is $11 million. Construction is expected to start later this year with completion date late in 1962.

Sweden

THE MATERIALS TESTING REACTOR, R2 began operating at Studsvik on May 4. The 30 MW pool-type reactor which cost £2,200,000 to build, will be mainly used to develop fuels for large power reactors. Fuel is highly enriched uranium, loaned by the U.S.AEC. A new tank is to be installed in the reactor later this year when a smaller reactor R2 O will also begin operating.



The first heat exchanger in position at Latina. The vessel was built in Italy to a design supplied by Head, Wrightson.

SMALL-SCALE ROCK HOLES are expected shortly to be made by the State Power Board in connection with experiments concerned with the construction of a rock-vessel reactor of the gas-cooled, graphite-moderated type.

Taiwan

NUCLEAR ENERGY LAWS and control regulations concerning peaceful uses of nuclear energy are being formulated by the Atomic Energy Council in Taipei. The Council has a swimming pool type reactor under construction and it is expected to be critical later this year.

U.S.S.R.

THE FIRST ice-breaking run has been completed by the nuclear propelled *Lenin*, with the arrival of the vessel in Murmansk after a 2,300-mile voyage. The ship is reported to have behaved well and as a result of the run, the first convoy in the Kara Sea will arrive 25 days ahead of schedule.

Yugoslavia

A TECHNICAL DELEGATION is visiting Yugoslavia from the United States to discuss nuclear activities.

U.S.A.

SUCCESSFUL INITIAL sea trials have been completed by the *Patrick Henry*, the second Polaris missile-firing nuclear submarine. The submarine is powered by the same capacity reactor as that of the *Skipjack* and was designed and developed by the Bettis laboratory in Pittsburgh. Westinghouse operate the laboratory. Another submarine developed by the laboratory, the *Scuplin*, was launched on March 31. This submarine is in the *Nautilus* class.

A HEARING was held during May by the AEC to show why Coastwise Marine Disposal should not receive a licence to receive, package and dispose of radioactive wastes.

AN EMPLOYEE of the Oak Ridge National Laboratory is reported to be suffering from erythema of the fingers and hand as a result of being exposed to radiation on March 8. Studies reveal that he received a beta dose of 5,500 rad to the dead outer surface of the skin. The dose was 2,000 rad at 2 mm below the skin surface. The erythema is abating, however, and the condition has not resulted in discomfort.

AUTHORIZATION has been given by the AEC to Fluor to preform architect-engineering services in connection with the modification of the OMRE at Idaho Falls. Expected to cost $1 million, the contract will include a new building to house the reactor, modifications of utilities systems and a laboratory and repair facilities. Atomics International operate the reactor for the AEC.

A PERMIT is to be issued by the AEC to Westinghouse for the construction of a critical experiment facility at Waltz Mill. The assembly will be arranged so that the fuel elements may be quickly rearranged for study purposes.

FIFTEEN PILLS of cobalt-60 with a specific activity of 308c/g are being used at the Argonne Cancer Research Hospital in Chicago. The pills were shipped from Idaho Falls after a four year baking period.

The main control of the *U.S.S. Triton*, the 5,900 - ton nuclear submarine which recently sailed 41,519 miles around the earth, undersea, in 84 days. The vessel followed the course of Ferdinand Magellan's circumnavigation of the earth in 1519-22.

A SET OF PROPOSED CRITERIA by which the AEC may relinquish and the states assume control of certain radioactive materials has been sent to the governors of the states by the AEC.

A THREE-DAY CONFERENCE on Reactions between Complex Nuclei was held in Gatlinburg, Tennessee, under the joint sponsorship of Oak Ridge and the American Physical Society. This was the second conference of this nature; the first was held in 1958.

A NEW PRICE LIST for boron-10 enriched up to 92% in the isotope B^{10} has been announced by the AEC, superseding all previous schedules.

A REVISED NOTICE has been published by the AEC regarding the base charges, special charges, specifications and packaging information for uranium hexafluoride.

GRAPHITE for the Experimental Gas-Cooled Reactor under construction at Oak Ridge will be supplied by National Carbon. The concern has been contracted by the AEC to supply 379,000 lb.

PROPOSALS are being sought from companies to produce enriched uranium billets for initial inventories for the New Production Reactor under construction at Hanford, Washington, by General Electric.

NONE OF FIVE PROPOSALS submitted in response to an invitation to co-operatives and public power organizations to operate a small nuclear power plant is completely acceptable according to the AEC. Two of the proposals, by Jamestown, New York and Dairyland Power Co-operative, LaGrosse, were acceptable but the sites offered were not fully satisfactory. These two proposers are being allowed another two months to suggest alternative sites.

PLANS FOR A NUCLEAR EXPOSITION and congress in Chicago by the Engineers Joint Council in 1961, have now been dropped. The only scheduled exhibition for 1961 is the AIF-ANS Atomfair in Chicago during November.

HEAVY WATER has been sold by the AEC to six countries. Canada bought 98,000 pounds; West Germany 71,000; Japan 20,000; Denmark 12,787; France 11,000; and Switzerland 10,000. India was leased 29,500 pounds and Denmark 22,046.

NUCLEAR PROPULSION components for three submarines are the subject of a $12,384,000 contract awarded by the U.S. Navy's Bureau of Ships to Westinghouse. The major items include reactor vessels, control drive and main coolant systems.

A COMBINED MEETING which will include the fourth conference on analytical chemistry in nuclear reactor technology and the first conference on nuclear reactor chemistry will be held at Oak Ridge on October 12-14.

A SLIGHT RISE in the radiation level in the Solid States Building at Oak Ridge resulted in evacuation of the building during April. The rise took place when an internal air flow carried radioactive particles consisting of graphite, contaminated mainly with cerium and strontium, from a process cell into the building. No escape of contamination occurred.

NOTICE OF INTENT to issue a permit to the Martin Company for construction of a critical experiments facility has been given by the AEC.

Chairman of the Argentine National Atomic Energy Commission being shown the Experimental Boiling Water Reactor (EBWR) on a recent visit to the Argonne National Laboratory in Illinois.

NEW BOOKS

Nuclear Reactor Stability. By A. Hitchcock, B.A., Ph.D., A.Inst.P. (Assistant Technical Manager, R. and D. Branch, U.K.AEA., Risley.) *Nuclear Engineering* Monograph Series. (61 pp., 8 illus., Temple Press Limited, 12s. 6d.)

"Reactor stability" is a phrase which is often casually—even glibly—used without a clear picture of its real significance. It is exceedingly important; it is also a subject of considerable complexity, if it is to be thoroughly mastered. Fulfilling the aim of *Nuclear Engineering* Monographs, this book steers skilfully between the Scylla of too little and the Charybdis of too much.

Internal stability, as the author points out in his preface, is of importance in that, if oscillation about a mean power is possible, the average power is reduced because constructional limitations require that components be designed to withstand the maximum value of the oscillation. This, of course, is quite apart from the deleterious effects of thermal cycling. An even more vital matter concerns the question of whether instabilities in a system can be reduced to within acceptable limits by the control system.

The book opens with the consideration of the dynamics of power reactors; the various coefficients of reactivity and the effect which changes in temperature, xenon concentration, and (in boiling reactors) voidage, will have, in stabilizing or destabilizing, and the order of their time scales. Chapter 2 is devoted to the stability of dynamic systems, i.e., the mathematical analysis of departures from the steady state. Chapters 3, 4 and 5 deal in detail with the instabilities due to temperature, xenon, and voidage, respectively, while the final chapter is devoted to a brief introduction to the principles of control. An appendix lists Green's Function for a flattened reactor, and other useful tables. There is a short bibliography.

N.E.T.S.

Approaches to Thermonuclear Power. By R. F. Saxe, B.Sc., Ph.D. (Reader in Nuclear Engineering, Queen Mary College, University of London). *Nuclear Engineering* Monographs Series (65 pp., 26 illus., Temple Press Limited, 12s. 6d.)

So much material, both popular and technical, has been written on the subject of thermonuclear power that it is difficult for those approaching the subject to pick their way between over-simplified (and occasionally over-optimistic) popular material, and fragmentary communications on some aspect of advanced plasma physics which they have not the background to appreciate. This book will provide that background.

Following a brief introduction on the potential advantages of controlled-fusion methods of power production, the author deduces the conditions necessary for the achievement of fusion, and the orders of temperatures necessary. Next, the behaviour of plasma at high temperature is studied, and the various types of instability and the interaction between plasma and magnetic fields are analysed. The third chapter deals with the linear pinch, and the reasons why a plain linear pinch falls short of serious attempts to produce a fusion reactor. After this, the elimination of the electrodes (and their attendant impurities) is dealt with, together with other significant improvements, in a chapter on toroidal machines. Chapter 5 gives an analysis of the basic principles of mirror machines. Finally, a short summary precedes the examination of problems which require clarification before a fusion reactor becomes feasible. There is a short bibliography for further reading. N.E.T.S.

The Shippingport Pressurized Water Reactor. By personnel of Naval Reactors Branch, U.S.AEC, Westinghouse Electric Corporation, and Duquesne Light Co. (600 pp., 163 illus., Addison-Wesley Publishing Co. Inc., 72s.)

Whatever place the pressurized water reactor may occupy in future power programmes there can be no doubt that the building of the first nuclear power station using the PWR as its heat source was a considerable achievement. This book, written by personnel of the Naval Reactors Branch of the U.S.AEC, the Westinghouse Electric Corporation, and the Duquesne Light Company, the scientists and engineers who designed, developed, built and tested the reactor, is a record of that achievement.

The technician will be interested to read of the basic reasoning that led to the choice of the plant parameters. The administrator will be particularly interested in the final chapters, which detail the organization that was set up to handle the various activities such as planning, tendering, buying, progressing, and training of personnel. He may be amused to read of the devices necessary to encourage contractors to submit realistic and firm bids for the manufacture of difficult and unusual items. The uninitiated may get an idea of the enormous resources in terms of manpower and money that are required to carry through a job of this nature.

At the time of its construction, the Shippingport reactor was unique in having a "seed and blanket" core; the seed built from plate elements of highly enriched uranium-zirconium alloy, and the blanket composed of rods of natural uranium oxide canned in Zircaloy. The new methods of calculation that had to be devised to guide the design, the ways of testing these calculations, the development and manufacture of the fuel and the job of building the core are described in three lengthy chapters. Methods of refuelling the reactor without removing the head from the pressure vessel were devised and the equipment that was produced to carry out the job is described. The major components of the reactor and its associated circuits, such as the pressure vessel, the pressurizer, the special leak-tight pumps and valves, the heat exchangers and the control rods, are dealt with in another chapter. Further chapters (there are 20 in all) cover instrumentation, the waste disposal system, the turbine specially designed for saturated steam, the problems of water chemistry, and the hazards evaluation.

Numerous line drawings and photographs supplement the text; the plant parameters are conveniently summarized in an appendix, and a bibliography of related reports is included. H.W.B.

Zone Refining and Allied Techniques. By N. L. Parr, M.I.Mech.E., F.I.M. (184 pp., 136 illus. George Newnes, Ltd., 40s.)

Ideas and standards of purity have changed considerably in recent years; while impurities were once regarded in terms of percentages, they are now considered—and measured—in terms of small fractions of parts per million. With the advent of new standards has come the realization that what were once written off as "trace" impurities may be of fundamental importance in determining the true characteristics of a substance; that, for example, the inherent brittleness of a metal may, in reality, be due to traces of foreign atoms hitherto considered insignificant.

Zone refining, the tendency of impurities in a molten substance to be "collected" by the travelling front of the solidifying zone, and concentrated in the last area to solidify, has been recognized in practice, if not in theory, since metal-workers in the dawn of history threw away the top portion of a cast ingot. It is only comparatively recently, however, that the theory of zone refining has been firmly established, and the associated techniques, amongst which may be mentioned the production of high vacua on a commercial scale and the development of induction heating, brought to the stage where the process can be considered to be of practical significance; in, for example, its wide use in the semi-conductor field.

The description "of practical significance" can also be applied to this book. The author, who is head of the Metallurgical Division of the Admiralty Materials Laboratory, while not neglecting the theory of the process, has emphasized the practical side, including the design and description of equipment ranging from the simpler—almost "lash-up"—demonstration rigs to quite complex apparatus for precision production work, and has also examined the allied subjects of the manipulation and examination of high-purity materials. In his final chapter, on the application of high-purity materials, future possibilities mentioned, such as fission product removal and improved ductility of beryllium, are of particular interest in the nuclear field.

J.A.B.-B.

Books Received

The British Engineers' Association Classified Handbook of Members. (Indexed in French, Spanish, Portuguese and German.) 31st edition. 608 pp. The British Engineers' Association (Inc.), 32 Victoria Street, London, S.W.1. 21s.

Basic Electricity. (In five parts.) The Technical Press, Ltd., 1 Justice Walk, Lawrence Street, London, S.W.3. 12s. 6d. per part, or 55s. per set.

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

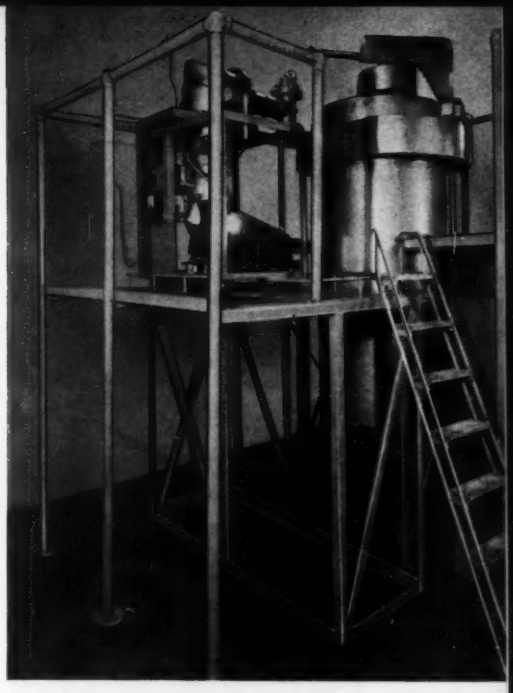
Vacuum Furnace Equipment

Special Edwards vacuum furnace equipment recently supplied to Atomic Power Constructions, Ltd., for development work on fuels, is of particular interest in that it was necessary to remove the furnace tube from the furnace without breaking the vacuum. This was carried out by fitting a quarter-swing butterfly plate valve to the water-cooled T-piece connecting the furnace with the pumping equipment, so that the whole could be disconnected and removed while still under high vacuum.

The furnace is a standard Royce Electric unit, with fully automatic temperature control, operating at 400°C, and the pumping equipment a 903B oil diffusion pump with a peak speed of 1500 litres/sec and an ultimate vacuum of 5×10^{-6} mm Hg, backed by a single-stage air-ballasted rotary pump.

(Edwards High Vacuum, Ltd., Manor Royal, Crawley, Sussex.)

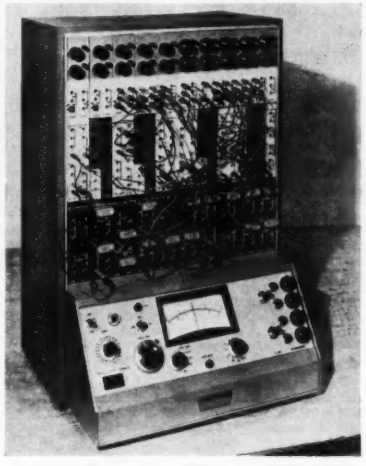
1309



The Edwards vacuum furnace equipment at A.P.C., Ltd

"Suitcase" Computer

Intended to supplement the slide-rule or the mechanical calculator, the PACE TR10 analogue computer is a compact transistorized device capable of solving differential equations with an operating accuracy said to be to 0.1%. The basic unit is pre-wired,



The PACE TR10 analogue computer.

and the necessary potentiometers, integrators multipliers, integration networks, amplifiers, function generators, etc., are of the plug-in type, so that the configuration of the computer may be changed, if desired; for example, additional non-linear components may be added. The standard unit is capable of solving up to two second-order differential equations, plus associated linear algebraic computations. For more complex problems, "expanded" versions, both linear and non-linear, are available.

Read-out equipment associated with this computer may take the form of a two-channel chart recorder, where a permanent record of any two simultaneous outputs against a time-base is desired. Alternatively, the PACE "Variplotter" may be used, providing continuous graphic recording of two variables, both X and Y scales being instantly variable over a wide range. The Variplotter can also be used independently, for graphic recording from digital information from a keyboard.

(Electronic Associates, Ltd., Victoria Road, Burgess Hill, Sussex.)

1310

Split Rotary Seal

As is generally recognized, the advantage of a rotary face-type seal is that wearing of the shaft does not occur, all wear being confined to the rubbing faces. A new Flexibox design, the "Sectaflex," utilizes split components, thus enabling replacement to be made to the worn parts without the necessity of stripping-down the machine, as is usual with the conventional design, and reducing maintenance of seals to a matter of minutes, instead of hours or days.

Accurate alignment of the seal faces at right angles to the shaft is effected by set screws in the seal plate, which is itself bolted to the stuffing-box casing, and it is claimed that leakage is reduced to a few cc's per hour. The seal can be used up to 100 p.s.i., and temperatures up to 300°F, provided that the vapour pressure of the fluid handled is less than atmospheric at operating temperature. A variation of the basic design is available which makes provision for positive circulation of the fluid past the working faces.

The Sectaflex split seal. Right to left, spring sleeve; spring; rotary seal ring body; split rotary seal ring packing; split rotary seal ring insert with solid locating ring; split stationary seal ring insert with solid locating ring; stationary seal ring body; seal plate with set screws for alignment.

(Flexibox, Ltd., Nash Road, Trafford Park, Manchester, 17.)

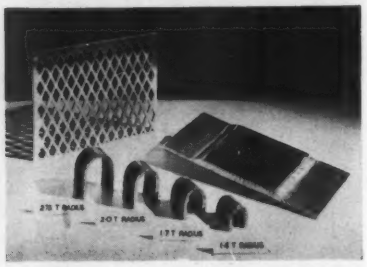
1311

Neutron Shielding Material

Improved formability is the characteristic of the "Hiduminium 400" series of dispersions of boron carbide in an aluminium matrix. Unlike conventional "Boral," the boron carbide is uniformly dispersed throughout molten aluminium instead of being produced by powder metallurgy techniques; the casting slab is then clad with high-purity aluminium and rolled. The boron carbide used has a purity of over 99%, and the concentration can be varied up to a maximum of 30% by weight, the particle sizes being between 80 and 200 mesh

as required; the cladding thickness may be as little as 5% each side.

Some idea of the formability of this material can be obtained from the illustration; it is possible to bend ¼-in. sheet cold around a radius of three times the thickness with 15% of boron carbide, or six times the thickness with 30% boron carbide. Welding of tubes and cylinders is also possible. The typical thermal conductivity for 15% boron carbide is approximately 320 B.t.u./ft²,h,°F, for 1 in. thickness.



Worked specimens of Hiduminium 400.

Standard sizes normally supplied are sheets 72 in. or 96 in. long and 36 or 45 in. wide over a wide range of gauges. For special applications, longer sheets can be produced, e.g., 180 in. × 45 in. × 0.18 in. thick.

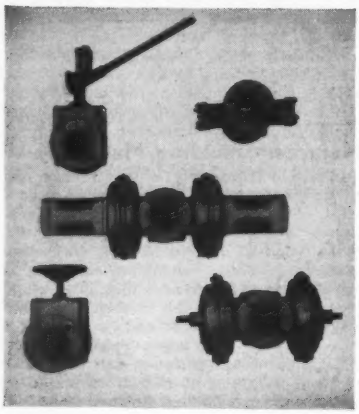
(High Duty Alloys, Ltd., Slough, Bucks.)

1312

Pinch Valves

Pinch valves, in which a flexible rubber sleeve is closed between two anvils, are now generally accepted for many difficult substances, such as corrosive and abrasive liquids and slurries. At first available in simple screw-down type, these valves can now be had with a wide range of operating mechanisms, including quick-acting lever, mechanical linkage, air or hydraulic cylinders, and pressure diaphragms. They are at present available in diameters of 1, 2 and 3 in., with six standard grades of sleeves reinforced for all working pressures up to 100 p.s.i. Hand operated valves are also available with 1½ in. and 4 in. bore. Air cylinder operated valves are available only in 2 in. size, but can be connected with taper adapters to existing pipe systems.

The range of Rowe pinch valves. (Top left) Lever operated. (Top right) Air cylinder operated. (Centre) "Air to open" diaphragm operated. (Bottom left) Hand operated. (Bottom right) "Air to close" diaphragm operated.

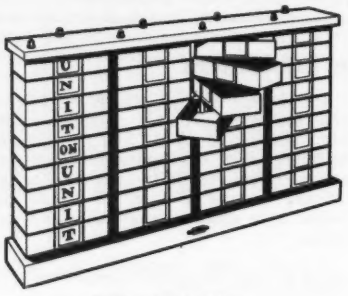


(W. H. Rowe and Son, Ltd., Quayside Road, Bitterne Manor, Southampton.)

1313

Small Component Storage

The Smallbone cabinet is a handy method of storing small components in an orderly fashion. Drawers are of the swing-open type, spring tensioned, 6 in. by 3 in., the depth being 1¾ in. or 2¾ in. as desired.



Smallbone unit cabinet.

Fifteen combinations are available, either in banks back-to-back or on top of one another. A cube arrangement on a revolving stand is also possible.

(Smallbone and Son, Ltd., 116 Raddlebarn Road, Sellyoak, Birmingham, 29.)

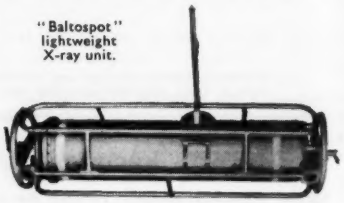
1314

Lightweight X-ray Unit

The "Baltospot" G300D industrial X-ray unit will examine steel up to 3 in. thick (300kV) and has overall dimensions of 40 in. by 9 in., with a weight of 142 lb. This is achieved by using pressurized inert gas for insulation and cooling; an internal blower gives forced circulation for anode cooling.

The operating voltage is 300kV and the unit can be supplied with either a conventional 40° solid angle beam insert with a fine focus (3 mm) or a 360° circumferential radiation insert tube. The unit and its control operate from a 220V 50-cycle supply and is fitted with direct reading kV and milliameters in addition to a synchronous timer. The voltage and tube current controls are continuously variable.

"Baltospot" lightweight X-ray unit.



The unit is complete with a telescopic centre finder of the fold-back type, end rings and protective cradle.

(Pantak, Ltd., Pale Road, Windsor, Berks.)

1315

Turbine Type Flowmeter

Under a new manufacturing agreement, de Havilland are manufacturing the "Pottermeter," a turbine flowmeter which, by using the kinetic energy of the fluid to be measured to support the rotor in a floating position does away with bearing friction, thus eliminating inaccuracies and speeding-up response time, the rotor speed being instantly proportional to the velocity of the flow through the unit. Inside the rotor is a small permanent magnet, polarized at right angles to the axis, so that the moving moment of the rotor causes an alternating current to be set up in a nearby coil. The frequency is thus directly

BRIEFLY . . .

Industrial Hydraulics, Ltd., 101 London Road, Reading, Berks, announce the addition of three new series of hydraulic accumulators to their existing range. Capacities are 8-20 gal at 2,000 p.s.i.; 1-8 and 8-20 gal at 5,000 p.s.i. All are of the gas-loaded type with a patented liquid-seal piston to prevent leakage of gas into the hydraulic system at times of shut-down. **(B 123)**

Telcleats, a new type of plastics cable cleat, are being manufactured by **The Telegraph Construction and Maintenance Co., Ltd.,** of Telcon Works, Greenwich, London, S.E.10. In black Telcothene, they are non-corrosive and flexible, and have good gripping properties. They are manufactured in 11 sizes to accommodate cable or piping from 0.5-in. to 2-in. diameter. **(B 124)**

More than 70 new semi-conductor devices, in 11 new series, are announced by **Texas Instruments, Ltd.,** Dallas Road, Bedford. They include solid-state switching thyratrons, computer diodes, voltage regulators, photo-diodes, temperature-sensitive resistors, and power transistors. **(B 125)**

Benson-Lehner (G.B.), Ltd., of West Quay Road, Southampton, announce a new ultra-speed ciné camera. Originally developed for photographing gas bubbles in turbulent fluids, the camera utilizes a rotating mirror and a Kerr cell-type of shutter, and has a maximum speed of 1,600,000 frames/sec on 35 mm film. **(B 126)**

Interesting features of the new 12-in. Univac pump developed by **Henry Sykes, Ltd.,** of Southwark St., London, S.E.1, include the addition of a separate vacuum pump for removal of entrained air, thus enabling the main impeller and volute to be designed without necessity for compromise between self-priming and pumping duties. Capacity is 3,500 gal/min against a total head of 32 ft, and the equipment is capable of handling large solids and abrasive sludges up to 60% solid content. **(B 127)**

A new fully automatic control table for the Muller M.G.150/300 industrial radiography unit has been developed, it is announced by **Research and Control Instruments, Ltd.,** Instrument House, 207 King's Cross Road, London, W.C.1. Main features include automatic adaptation to the characteristics of two or more tubes with different loading data, overload protection, mains voltage compensation, stabilization of tube voltage, and an electrically reset auto-timing device. **(B 128)**

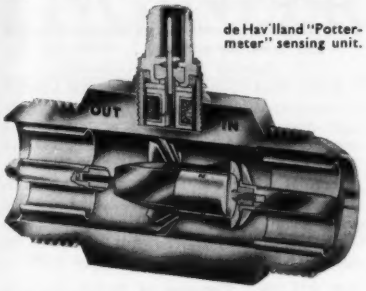
A sub-miniature 3-pin plug and socket, type SM3, particularly suitable for transistor circuits, weighing only 0.06 oz, with body dia of approx ⅛ in., has been developed by **Electro Methods, Ltd.,** Caxton Way, Stevenage, Herts. **(B 129)**

British Indicators (Sales), Ltd., of Sutton Road, St. Albans, Herts, have developed the John Bull super-sensitive dial indicator, with hardened and lapped pinions and a balanced pointer, said to achieve a degree of sensitivity and accuracy better than any dial indicator yet produced. They are manufactured in 1½-, 2-, 3- and 4-in. sizes, and guaranteed to B.S.907. **(B 130)**

George Kent, Ltd., Luton, Bedfordshire, have recently developed a new solid-state reference source, to provide a stable ripple-free d.c. output of 5mA at 5V for the slidewire of their range of self-balancing recorders and controllers. Operating from 200-250V 40-60 c/s mains, the output variation is said to be less than 0.05% for a supply variation of 10%, or a temperature variation of 30°C, while the maximum output ripple is given as 0.01% rms. **(B 131)**

Another Kent development is a transistorized quadrature suppressor, for use with a.c. servo systems, to eliminate the quadrature component which can arise in this type of system giving an error signal. **(B 132)**

proportional to the rate of flow. The output from this sensing element is applied to an electronic frequency converter and flow is directly indicated or recorded. The meter may also be used for control purposes.



de Havilland "Potter-meter" sensing unit.

The size available is from ½ in. up to 22 in. diameter, covering a flow range of 0.1 gal/min to 40,000 gal/min although larger sizes can be supplied if required. The normal constructional material is stainless steel.

It is stated that accuracies of ±0.1% can be obtained. The instrument will withstand a wide range of pressures and temperatures and the average response time is stated to be about 10 m/sec.

(de Havilland Propellers, Ltd., Hatfield Aerodrome, Hatfield, Herts.)

1316

Safe Lifting Clamp

Of interest to those responsible for the fabrication of pressure vessels is the plate-lifting clamp developed by Interlas N.V. of Holland, and now available in the U.K. Cam operated, the Interlas clamp will not slip under load, or release, even when the load touches the ground, until required. It is suitable for horizontal or vertical lifting, and is made in seven sizes, from 1½-20 tons, and plate thicknesses of ¼ in.-3 in.

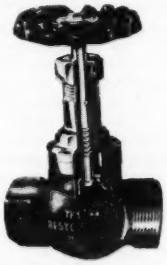
The Interlas lifting clamp.

(Interlas Ltd., 9 Church Street, Ampthill, Bedford.)

1317

Multi-purpose Globe Valve

Six types of valve with a single standard body are among the good features of the new Bestobell "Two-Five-O," recently introduced in screwed and flanged types for pipe sizes from ¼ in. to 3 in. Both the plug portion and the valve seating are quickly removable, and it is possible to obtain mitre, shrouded, or needle valves, in stainless steel with a stellited seat, asbestos or rubber disc seats, or O-ring closure with metal seat. No special tools are required for removing the valve seating, which can be done with either a square or octagon steel bar.



Bestobell "Two-Five-O" valve.

Other good features include a back seating device so that with the valve fully open the main gland can be repacked while under pressure.

(Bell's Asbestos and Engineering, Ltd., Bestobell Works, Slough, Bucks.)

1318

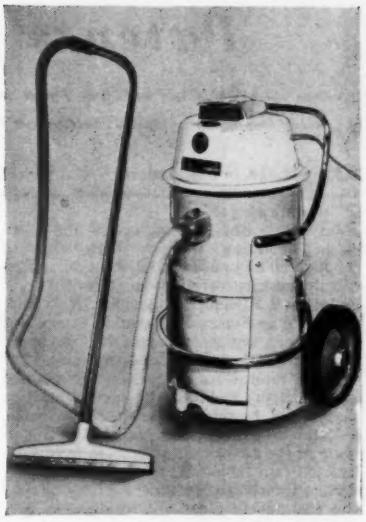
Trip Amplifier

A sensitive and accurate warning and trip system has been developed to operate from small d.c. inputs such as thermocouples. The complete trip unit comprises an amplifier and transistor power supply in a single mounting frame which houses the trip setting potentiometer, alarm lamps, relays, etc., with, if required, a pre-trip warning, set at a fixed level below the trip point. Trip levels may be set to an accuracy of 0.1% and there are six standard input current voltage ranges available from 0-10 μA to 0-30 mA and 0-10 mV to 0-150 mV. Range-changing is possible by plug-in range cards.

(Left) Elliott trip amplifier.

(Elliott-Automation, Ltd., 34 Portland Place, London, W.1.)

1319



(Right) "Jetstream" cleaner unit.

Heavy-duty Vacuum Cleaners

The "Jetstream" cleaner, which can be used on wet or dry work, has a three-stage fan unit giving an air flow of 144 ft³/min with a vacuum of 51 in. w.g. with a ⅜ in. orifice at the end of a 10 ft hose. The filter surface has an area of 1,200 in.², and for dry work has a flannel cloth base; for wet work, a new type of plastics-impregnated cloth is provided. Special filters are also available to meet unusual conditions. Retained waste, dry or wet, is housed in a tank which is easily removed for emptying. While the main filter removes all visible particles, a sub-micron fibre glass filter of 200 in.² can be supplied for nuclear or hospital work when required.

(Kent Floor Machine Co., Ltd., Speke, Liverpool, 24.)

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CATALOGUES

The April 1960 issue of *Platinum Meta's Review* published by **Johnson, Matthey and Co., Ltd.**, contains an article on new developments in bright platinum plating. (Hatton Garden, London, E.C.1.)

The Water Treatment Division of **Head Wrightson Processes, Ltd.**, have issued the first of a series of water treatment publications. This covers softening equipment manufactured under licence from the Belco Industrial Equipment Division of Paterson N.J. (Ship House, 20 Buckingham Gate, London, S.W.1.)

Equipment for semi-conductor crystal pulling is described in the March 1960 issue of the *Wild-Barfield Heat-Treatment Journal*, which also contains information on electric drying equipment. (Otterspool Way, Watford By-pass, Watford, Herts.)

Three new publications have been received from **Henry Wiggin and Co., Ltd.** Possibly of most general interest is the new edition of "Welding, Brazing and Soldering of High-Nickel Alloys." This, in addition to recommended preparation of welds, gives information on oxy-acetylene, metal-arc, inert gas, shielded, atomic hydrogen, resistance and flash-butt welding. A sixth edition of "The Nimonic High-Temperature Alloys" gives complete tables of properties of the Nimonic 75, 80A, 90 and 105 alloys, originally designed for gas turbine work, with detailed data on creep properties.

The third, "Nimocast Heat-resisting Alloys," gives main properties of cast alloys, which, in many cases, are identical with the Nimonic series. (Thames House, Millbank, London, S.W.1.)

The Semiconductor division of **Mullard, Ltd.**, have issued a Designer's Guide which gives essential data on Mullard transistors, rectifiers and diodes. Revisions of this guide are to be issued three times a year. (Mullard House, Torrington Place, London, W.C.1.)

Properties of Polypenco P.T.F.E. are given in a new publication received from **Polypenco, Ltd.** (68-70 Tewin Road, Welwyn Garden City, Herts.)

Two new leaflets describing their range of liquid storage tanks have been received from **Mackland and Scowcroft, Ltd.** (Cox Green Works, Bromley Cross, near Bolton, Lancs.)

A catalogue received from **Servomex Controls, Ltd.**, describes several new products, including a stabilized d.c. power supply unit, high-precision motor speed controller, components for servo mechanisms and an oxygen analyser.

High efficiency dust collection is described in "Ambuco Cyclones," a new publication from **Ambuco, Ltd.**, a subsidiary of Buell Engineering Co., Inc. of U.S.A. (Standbrook House, 2-5 Old Bond Street, London, W.1.)

The range of temperature measuring instruments manufactured by **James Gordon and Co., Ltd.**, is described in a new catalogue (182), covering industrial applications. (Dalston Gardens, Stanmore, Middlesex.)

Primary elements for temperature measurement, boiler test indicators, instrument panels, and flow-measuring instruments of the "Commander" KU series are described in three new publications received from **George Kent, Ltd.** (Luton, Bedfordshire, England.)

A new publication, "Wrought Zirconium," is to hand from the Metals Division of **Imperial Chemical Industries, Ltd.** Properties of zirconium and its alloys, the range of wrought products and their availability are listed; there is also a section on hafnium. Other I.C.I. publications received cover the physical and mechanical properties and the fabrication of titanium and its alloys. (I.C.I. House, Millbank, London, S.W.1.)

"The Metal Way" is the title of a bound publication received from **AB Svenska Metallverken** illustrating the activities of some of the main Swedish companies which are members of the Group, some of which have been in existence since the early 17th century. (Skultuna, Sweden.)

A souvenir book, "The Allen West Story," has been issued by **Allen West and Co., Ltd.**, to celebrate 50 years in the electrical manufacturing industry. (Brighton 7.)

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 820,424. Evaporators. P. Waine, D. E. Abel. To: Atomic Energy Authority.

An evaporator for continuous and automatic operation with a high rate of production of concentrated solution. Electrically conductive solution is boiled in a boiler by R.F. induction heating. A mixture of vapour and entrained solution passes into a cyclone separator and the separated vapour to a condenser and dump tank. The solution returns to the boiler, the gradual increase being measured by a concentration meter. On reaching a predetermined value a solenoid-operated valve opens and allows some of the concentration to pass to a sump tank. Fresh solution from a feed tank simultaneously enters the boiler by gravity and the diluted solution continues to boil. When the dilution reaches a certain degree the meter shuts the passage to the sump tank. A fall in the level of solution in the feed tank uncovers a high-level probe breaking an electric circuit causing the entry of fresh solution into the feed tank. The solution from the sump tank is also automatically passed on through an intermediate tank to the storage tank. The concentration meter may be of the gamma-ray absorption type.

B.P. 820,554. Heat exchanger. D. A. R. Dobbins, P. G. Davies. To: G.K.N. Group Services Ltd.

The exchanger is of the type with a plurality of water-like passageways alternately communicating with inlet and outlet ducts for a primary fluid and inlet and outlet ducts for a secondary fluid. The passageways of the two groups are interleaved and the fluids travel in counter-flow. When welding the plates directly it is very difficult to detect or repair any leaks. The difficulty is overcome by uniting the plates to spacer elements between the peripheral margins of the plate (e.g., by the argon arc process without filler metal, or in a furnace after coating the faces of spacer elements and plates with metal liquefied at the furnace temperature). The required gaps are formed by removing part of the material of the spacer elements; here spark machining is a particularly advantageous method.

B.P. 820,579. Nuclear reactor. A. T. Bowden. To: C. A. Parsons and Co., Ltd.

The nuclear fuel is housed in a plurality of re-entrant tubes each comprising an inner and an outer tube. The inner tube contains the fuel, liquid coolant is circulated through a space between inner and outer tube and thence through the inner tube to cool the surface of the nuclear fuel. The flow areas for the coolant through the inner tube and the space between the tubes are so adjusted that the velocity of the liquid through the space is lower than its velocity through the inner tube. The outer walls of the re-entrant tubes contain gas spaces and the cooling liquid flows in a closed pressurized system.

B.P. 820,584. Radioactive tracer. To: Esso Research and Engineering Co. (U.S.A.)

A subdivided solid plated with radioactive gold.

B.P. 820,614. Coating of metal surfaces. A. Blainey, M. L. Noakes. To: U.K. Atomic Energy Authority.

Erosion-resisting coatings, remaining tough up to 900°C are formed by applying powdered zirconium, zirconium-rich alloy or zirconium hydride in admixture with an evaporable binder (organic liquid) to the clean metal surface, heating the metal to at least 900°C, in vacuo or inert atmosphere, to cause diffusion of zirconium into the metal and allowing the resulting coated metal to cool in vacuo. This may be applied to ferrous metals and alloys, particularly with chromium.

B.P. 820,660. Treatment of plutonium-aluminium fuel rods. To: Atomic Energy of Canada, Ltd. (Canada.)

Plutonium and transplutonium products are recovered for re-use by heating a plutonium-aluminium alloy with bismuth, in an inert atmosphere, at a temperature above the melting point of the material, preferably 800-1,150°C to transfer the products to the bismuth phase from the alloy phase. The melt is then cooled to below 660°C but above 270°C to solidify the aluminium. The molten bismuth phase is poured out and the solidified phases separated mechanically.

B.P. 820,670. Desheathing of uranium fuel rods. To: Atomic Energy of Canada Ltd. (U.S.A.)

The sheath of zirconium or an alloy thereof is scored at many points to expose the uranium core, and the rod is then treated with steam of not less than 250°C to oxidize the uranium. This is continued until the sheath has been freed from the uranium. The greater the number of punctures or scores the more rapid the rate of separation. A preferred temperature range is 340-380° C. The steam should be applied under pressure.

B.P. 821,091. Electrodeposition of beryllium. A. R. Gibson. To: U.K. Atomic Energy Authority.

Beryllium is electrodeposited from a molten alkali metal chloride bath containing beryllium ions and a sulphide at a temperature of 450°C.

B.P. 821,188. Compensated ionization chambers. J. Weill. To: Commissariat à l'Energie Atomique. (France.)

Ion chambers for detecting and measuring neutron fluxes, in particular in nuclear reactors. Such chambers have at least two main elementary chambers, one responsive to the neutron flux, the other responsive only to the effects of other radiations, and serving to compensate for the effects of these other radiations in the first chamber. The compensation of the main chamber is improved by the addition of at least one auxiliary chamber the output of which is adjustable. In a preferred arrangement, the auxiliary ionization chamber is constituted by the spaces between the areas of alternate (parallel) plates, the dimensions of which can be adjusted by angular displacement of one of the plates about an axis perpendicular thereto.

B.P. 821,263. Fuel elements for nuclear reactors. K. H. Dent, D. J. Dawson. To: U.K. Atomic Energy Authority.

Use of vaned split rings around the element in its channel to restrain bowing of the fuel element.

B.P. 821,287. Cermets comprising uranium and uranium carbide. J. Williams. To: U.K. Atomic Energy Authority.

It has been found that, if uranium powder is compacted with powered carbon in certain proportions and then sintered at a temperature below the melting point of uranium but high enough to cause reaction, a cermet structure is formed of a continuous matrix of uranium mono-carbide and within it particles of uranium metal. This is a suitable material for fuel elements operating at high temperatures up to 1,100°C.

B.P. 821,289. Removal of fission products from nuclear reactors. H. Chilton. To: C. A. Parsons and Co., Ltd.

Continuous removal from a liquid metal fuel reactor is obtained by heating a portion of the fuel by fission within the reactor core to a high temperature above that of the remainder of the fuel and causing this portion to circulate towards the free surface of the fuel (by convection or by a vacuum above the surface). The fall in pressure causes the liquid metal to boil, freeing volatile fission products.

B.P. 821,297. Homogeneous fuel elements for nuclear fission reactors. To: Deutsche Gold- und Silber-Scheideanstalt vorm. Roessler. (Germany.)

Processing of depleted fuel elements is difficult if the particles of the fissile materials are contaminated with fission products. These difficulties can be avoided by making the fuel elements of fissile or fissile and fertile materials, or their compounds, in a practically homogeneous mixture with solid filler substances, which may also act as a moderator, in the form of particles of a grain size between 5 and 12μ. Solid fission products are then retained in the fillers.

B.P. 821,367. Neutron detectors. To: Commissariat à l'Energie Atomique. (France.)

The detection of neutrons in the presence of intensive gamma-ray flux requires special apparatus which does not give very accurate measurements. A conventional radiation counter (proportional counter, Geiger counter, scintillation counter) can be used if the fission products are conveyed by means of a gas stream (air, carbon dioxide, nitrogen) to a counter placed at a suitable distance (several metres) from the parasitic (gamma ray) flux. The gas stream is caused to flow through a chamber containing a target which carries a layer of a fissile material to be subjected to the action of the neutron flux.

B.P. 821,639. Fissile materials for use in nuclear reactors and method of manufacturing such materials. To: Commissariat à l'Energie Atomique. (France.)

An alloy of uranium and at least one metal of the group aluminium, zirconium, chromium, titanium, vanadium, up to 2% by weight finely dispersed in the mass of uranium has improved mechanical properties in comparison with pure uranium metal. A second metal different from the first group (from which only one metal should then be present) may also be added. This second metal belongs to the fifth period, i.e., zirconium, niobium, molybdenum, technetium, ruthenium, rhodium, tin, antimony, and its amount should not be more than 1% by weight.